Shasta River TMDLs

Meeting of the Technical Advisory Group and Interested Pa

April 18, 2005

California Regional Water Quality Control Board
North Coast Region

Purpose of Meeting

- To update the group on the status of Shasta River temperature and dissolved oxygen TMDL efforts

- To get your input

- To answer your questions

Outline

- Introductions
- TMDL scope, schedule, and status
- Analytical tools – scope and status
  - Water quality model
  - Benthic algae model
  - Mass balance, mixing, and residence time calculations
  - Productivity calculator
- Water quality model scenarios
- Geographic information analysis
- Implementation Plan concepts
- Feedback – Q &A

Introductions

TMDL Scope

- Temperature and dissolved oxygen TMDLs
  - Water quality objectives
  - Beneficial uses
- Applies to Shasta River watershed
- Determine sources and quantity of pollutants the river can receive and still meet standards
- Develop plan to attain and maintain standards

TMDL Schedule

- Public meeting on draft TMDL Report – July 2005
- Peer review of draft TMDL Report - August 2005
- Public review of TMDL Report – October 2005 (60 days)
- Regional Water Board Workshop on TMDL – November 2005
- Regional Water Board Hearing on TMDL – January 2006
- State Water Board Workshop and Hearing on TMDL – June 2006
- EPA approval of TMDL – January 2007
- TMDL implementation – February 2007

Available Work Products

http://www.waterboards.ca.gov/northcoast/programs/tmdl/shasta/shasta.html

- Shasta River Dissolved Oxygen TMDL Work Plan
- Shasta River Water Quality Conditions – 2002 & 2003
- Shasta River Water Quality Related Investigations – 2004
- Lake Shastina Limnology (Watercourse)

Shasta River Modeling

- TVA RMS: Extension of Abbott (2002) to include
  - Dissolved Oxygen
  - Forcing Functions
    - Biochemical Oxygen Demand
    - Nitrogeneous Oxygen Demand
    - Sediment Oxygen Demand
    - Attached Algae Standing Crop
- Analytical “Toolbox”

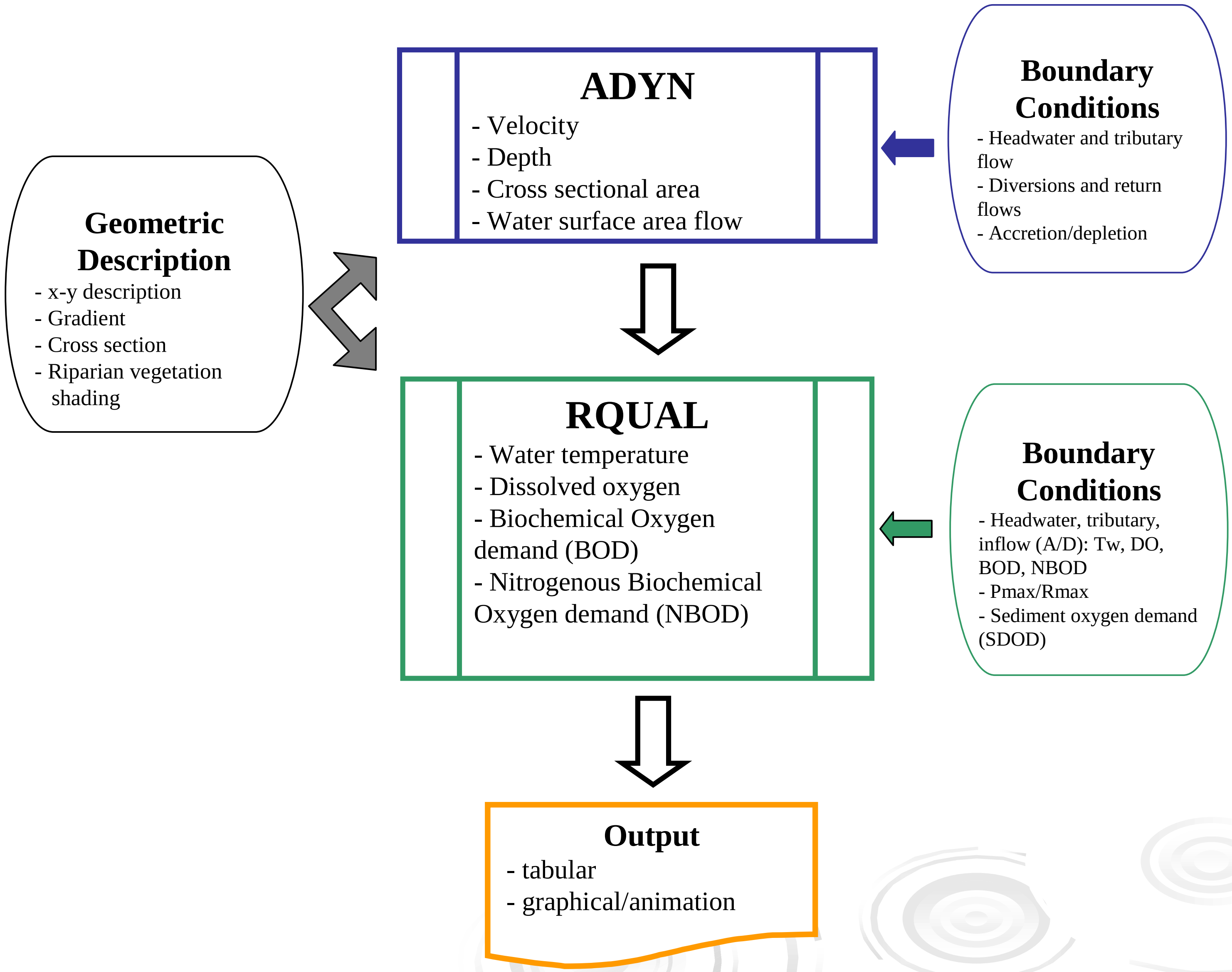
TVA-RMS

- Two models
  - ADYN: Hydrodynamics (Flow)
  - QUAL: Water Quality
    - Temperature
    - Dissolved oxygen
    - Biochemical Oxygen Demand
    - Nitrogenous Biochemical Oxygen Demand
    - Specified:
      - Sediment oxygen demand
      - Attached Algae
      - Temperature
- One-dimensional model, finite difference model

Previous Flow and Temperature Modeling Work

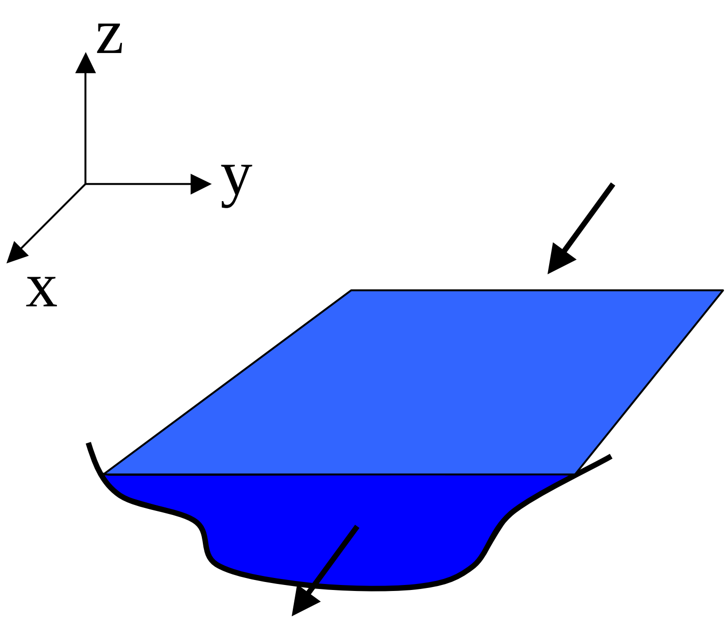
- U.C. Davis (1997) [RCD; SWRCB 205(j)]:
  - Data inventory
  - Riparian vegetation inventory
  - Flow and temperature modeling
- Abbott (2002) [RCD; CDFG, USFWS]:
  - Application of TVA RMS for flow and temperature
  - Modification to shade routine

TVA RMS Framework



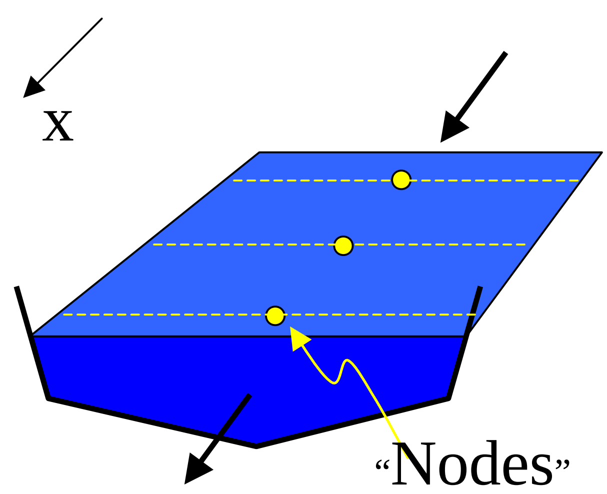
RMS Model Representation

Prototype



Model

Depth averaged: z
Laterally averaged: y



River Representation

Modifications

- Riparian Shading (Abbott, 2002)
- Modified input geometry
  - FROM: Abbott, 2002
  - TO: Lamphear, 2004
- Geometry modifications required updating
  - Flow
  - Water quality
  - Shading

Model Calibration

- Calibration State Variables
  - Flow
  - Temperature
  - Dissolved Oxygen
- Calibration/Validation Periods:
  - 9/17/2002-9/23-2002 (Cal)
  - 7/02/2002-7/08/2002 (Val)
  - 8/29/2002-9/04/2002 (Val)

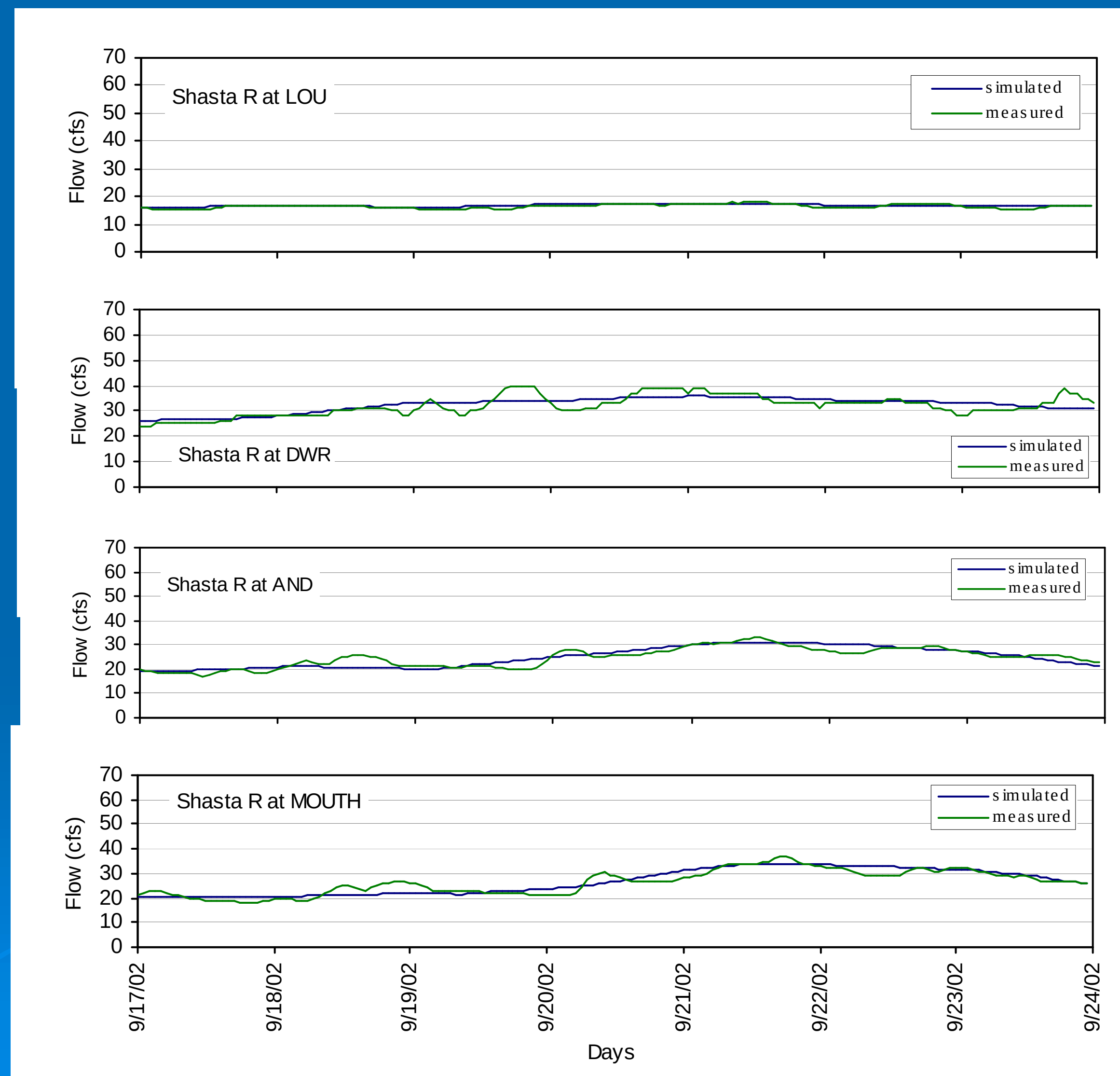
Flow

Louie Road

DWR Weir

Anderson Grade Rd

Mouth



9/17/2002-9/23-2002

Temperature

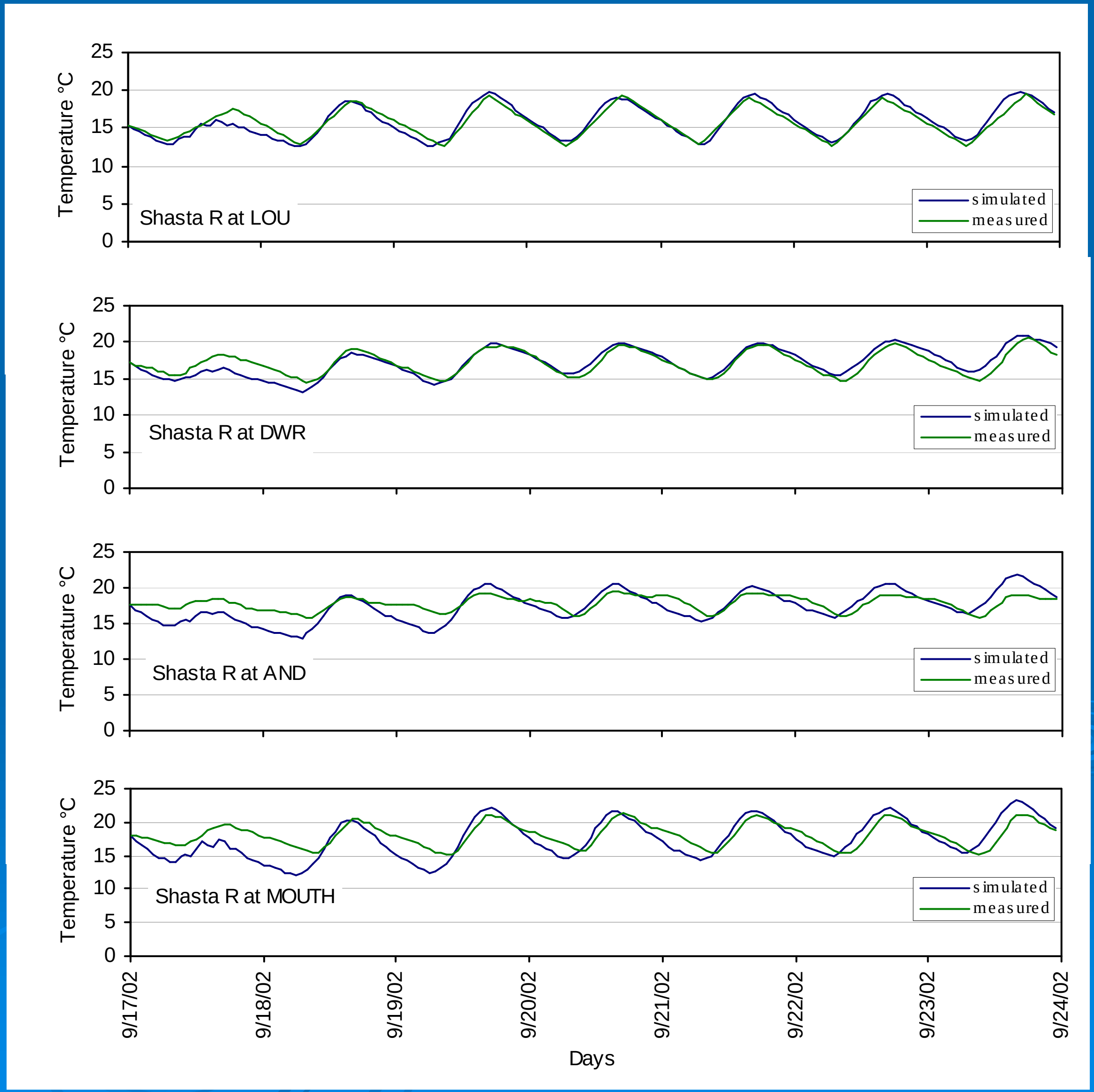
Louie Road

DWR Weir

Anderson Grade Rd

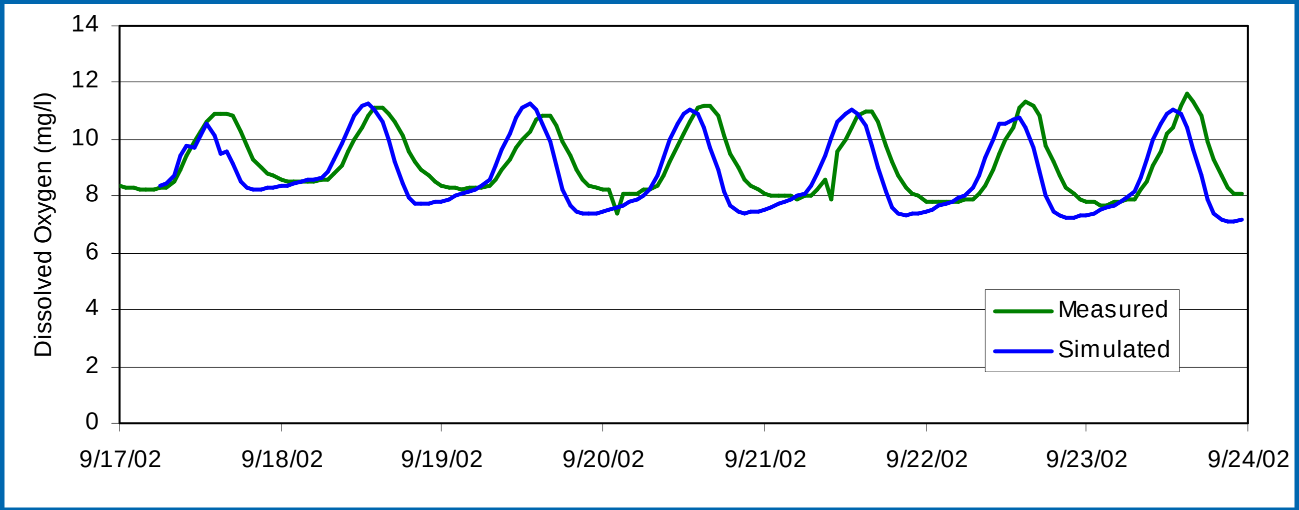
Mouth

9/17/2002-9/23-2002

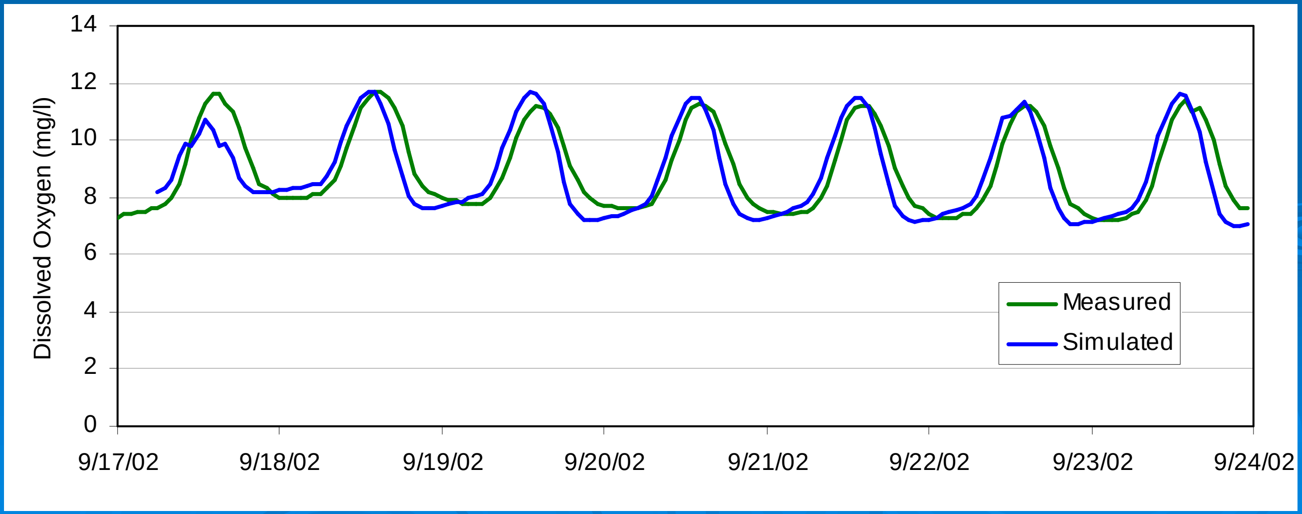


Dissolved Oxygen

DWR Weir (USGS)



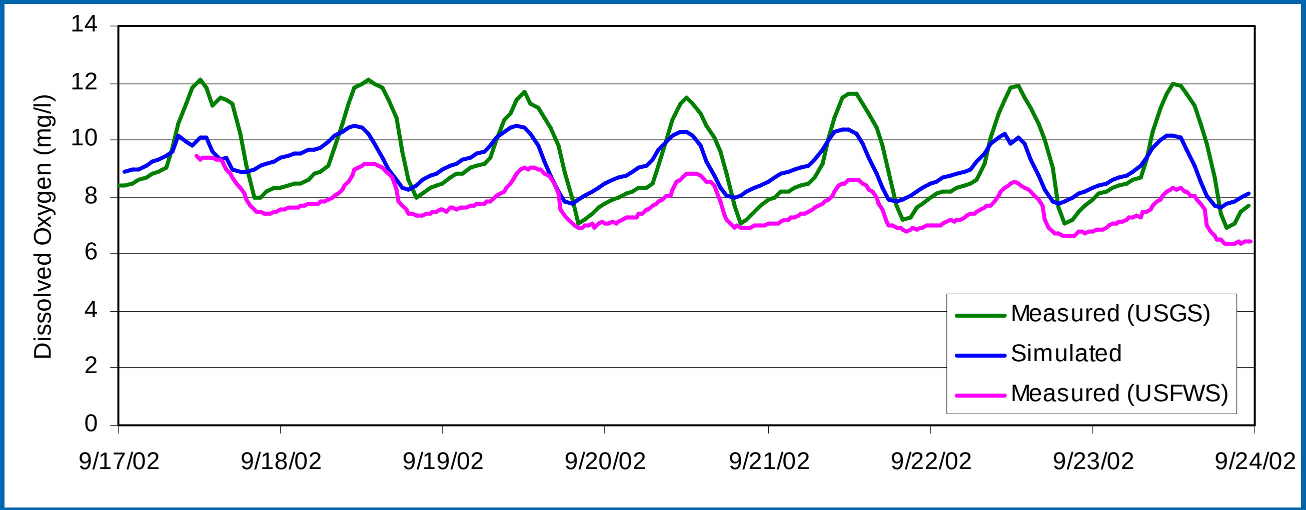
Highway 3 (USGS)



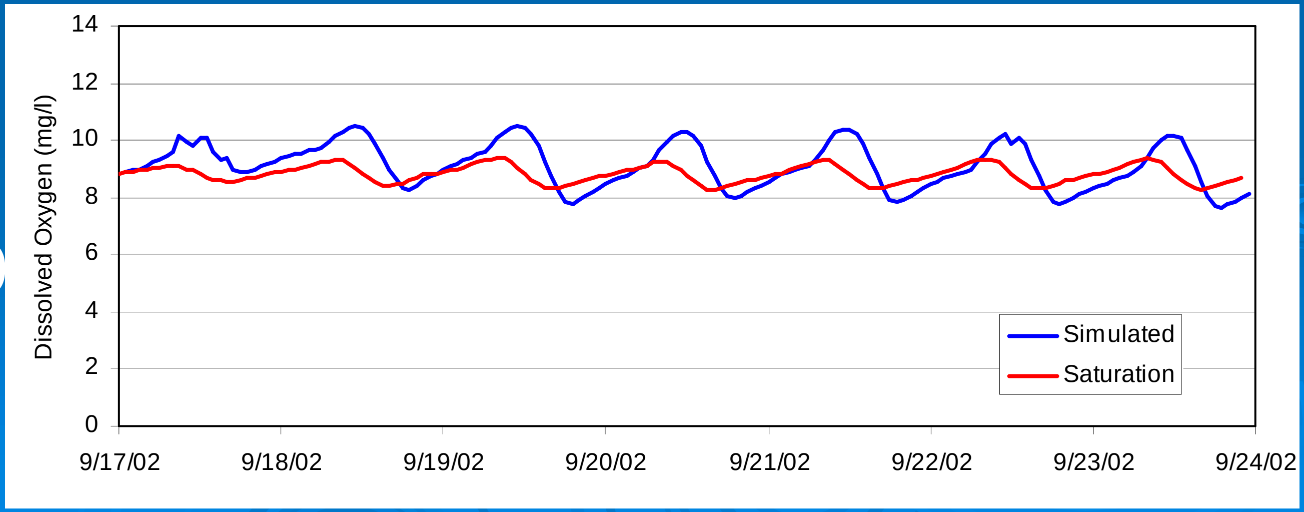
9/17/2002-9/23-2002

Dissolved Oxygen

Shasta River Near Mouth (USGS/USFWS)



Shasta River Near Mouth (Saturation calc)



Calibration Report

- Model implementation, updates, modifications, methods
- Available data
- Model parameters and final values used
- Graphical and statistical presentation
- Sensitivity analysis

Analytical Toolbox

- Objective: compliment RMS in the assessment of water quality
- Toolbox
  1. Benthic Algae Model
  2. Mass Balance
  3. Residence Time
  4. Mixing Model
  5. Primary Productivity Calculator

1. Benthic Algae Model

- Objective: determine algae response to light and nutrient conditions
- Mass balance model was a volume-based model

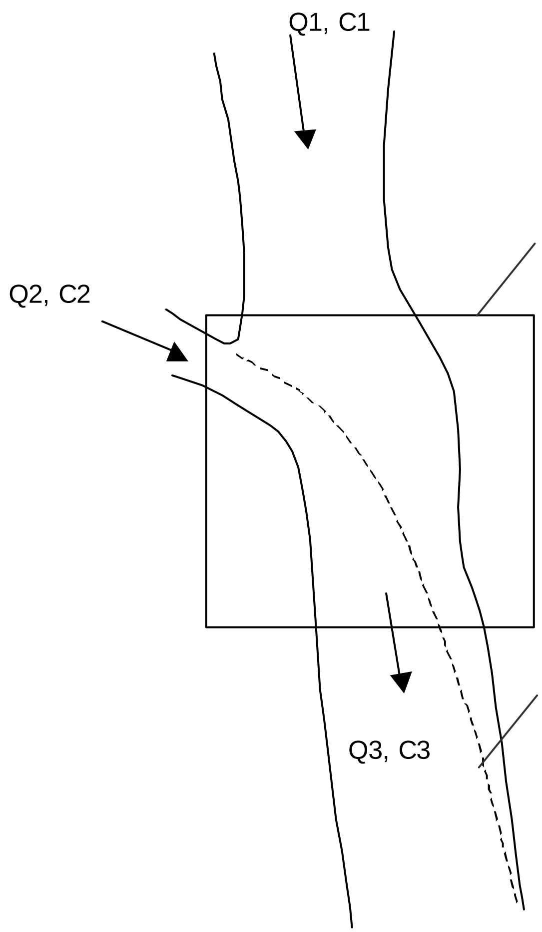
$$P_{t+\Delta t} = P_t + \Delta t\left((\underbrace{\mu_{\max} LF}_{\text{Growth}} - \underbrace{R_b}_{\text{Resp}} - \underbrace{D_b}_{\text{Mort}} - \underbrace{Z_b}_{\text{Graz}})P_t - \underbrace{\frac{s\,v P_t}{d}}_{\text{Scour}} \right)$$

LF = f(T, Light, N, P, Si, C)

- Logic based on QUAL2
- Initial application indicates Shasta River is sensitive to light and to a lesser extent nutrients (particularly nitrogen)

2. Mass Balance

- **Objective: estimate impacts of inflows on mainstem water quality**



Control Volume

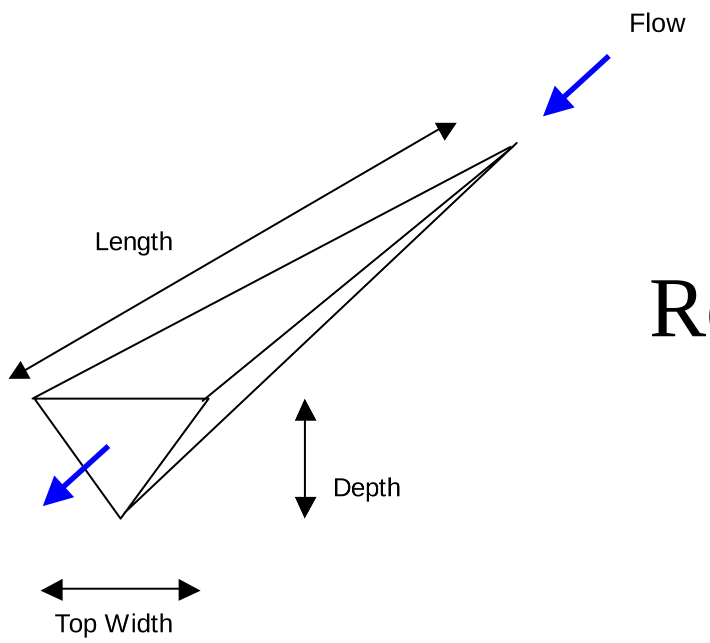
<u>Idealized</u> instantaneous and complete mixing (i.e., no reaction, sources or sinks active)

$$C_3 = \frac{(Q_1C_1 + Q_2C_2)}{Q_3}$$

Actual "mixing zone"

3. Residence Time

- Objective: estimate residence time of impoundments



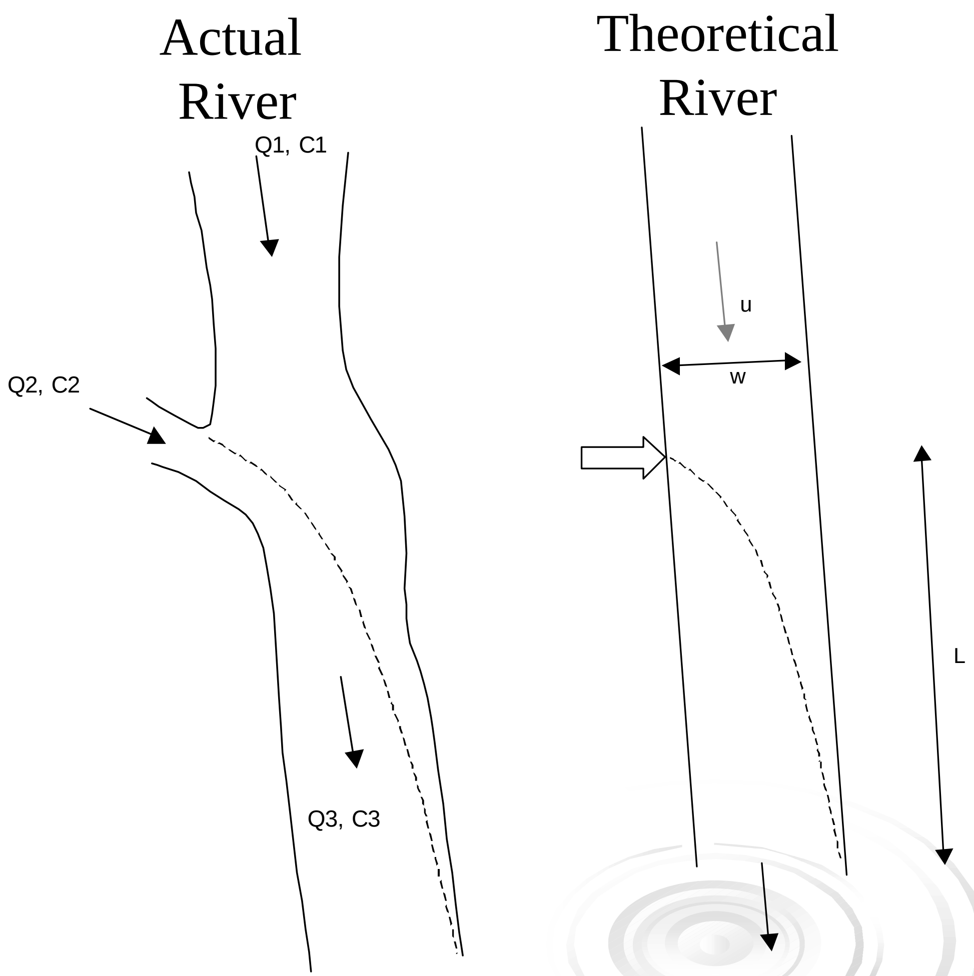
Residence Time, $\Theta = V/Q$

V = reservoir/reach volume $[L^3]$

Q = flow $[L^3/T]$

4. Mixing Zone

- Objective: estimate mixing length of inflows (conservative)



$$L = \alpha u W^2/(\varepsilon_t)$$

(Fischer et al, 1979)

L = mixing length
α = 0.1 center
0.4 side
u = velocity
W = width
$\varepsilon_t = \beta d u^*$
β = 0.1-0.8
d = depth
$u^* = (gdS)^{1/2}$
g = gravity
d = depth
S = bed slope

5. Productivity Model

- Objective: estimate photosynthesis and respiration rates of standing crop for RMS
- Kansas Biological Survey Model
- Estimates photosynthetic rate based on specified
  - Dissolved oxygen
  - Temperature
  - Velocity
  - Depth

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Scenarios

1. **Riparian Shading**
2. **Dwinnell Dam releases**
3. Impoundment Effects
4. **Return flows**
5. Yreka Creek
6. Increased Flows
7. **Benthic Algae**
8. “Plumbing” changes
9. Combination to meet water quality objectives and targets

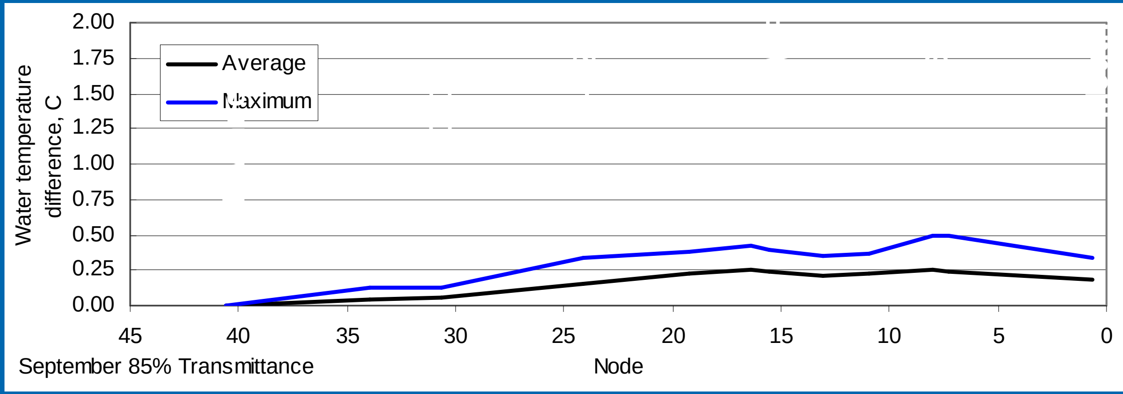
Bold: completed preliminary analysis, all others in progress

Riparian Shading

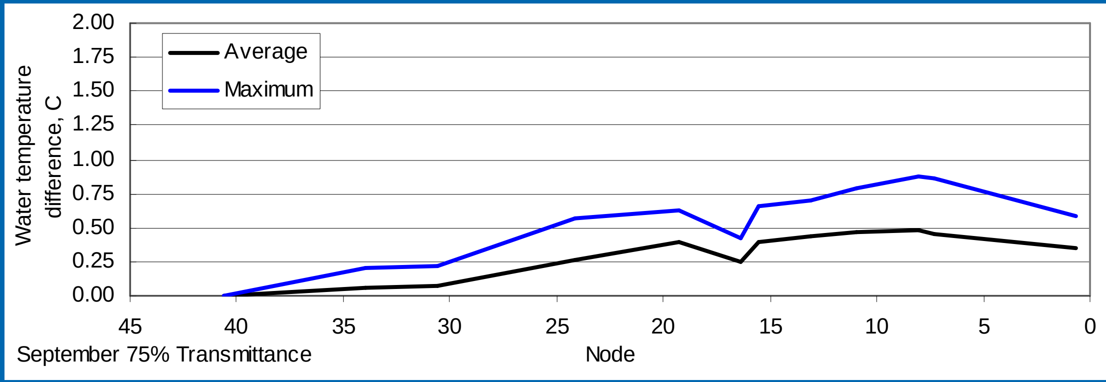
- <u>Objective</u>: Identify role of shading on water temperature (reduced solar radiation) and dissolved oxygen (reduced algal production)
- <u>Preliminary Findings</u>:
  - Water temperature: increased shade leads to overall lower mean, min, and maximum daily temperature
  - Dissolved oxygen: increased shade tends to
    - Decrease daily maximum
    - Increase daily minimum
    - Increase daily mean (due to lower Tw and assoc. higher DO saturation)

Riparian Shade: Temperature

Herbaceous (85%)

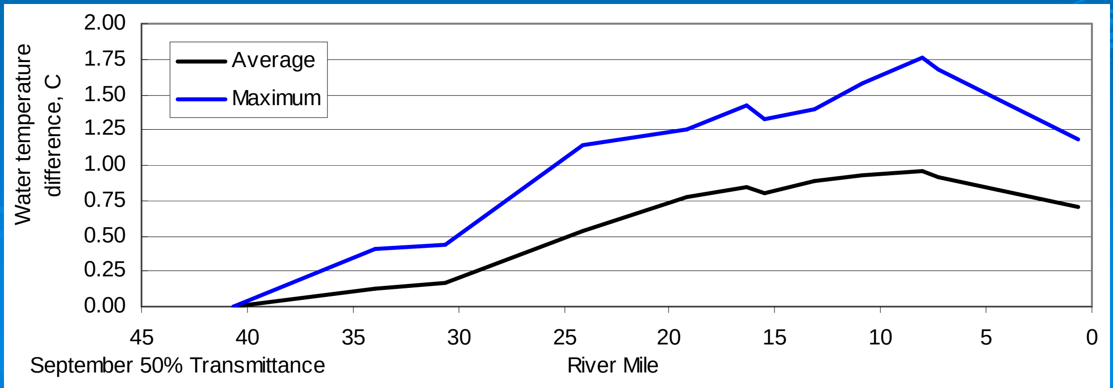


Woody Riparian (75%)



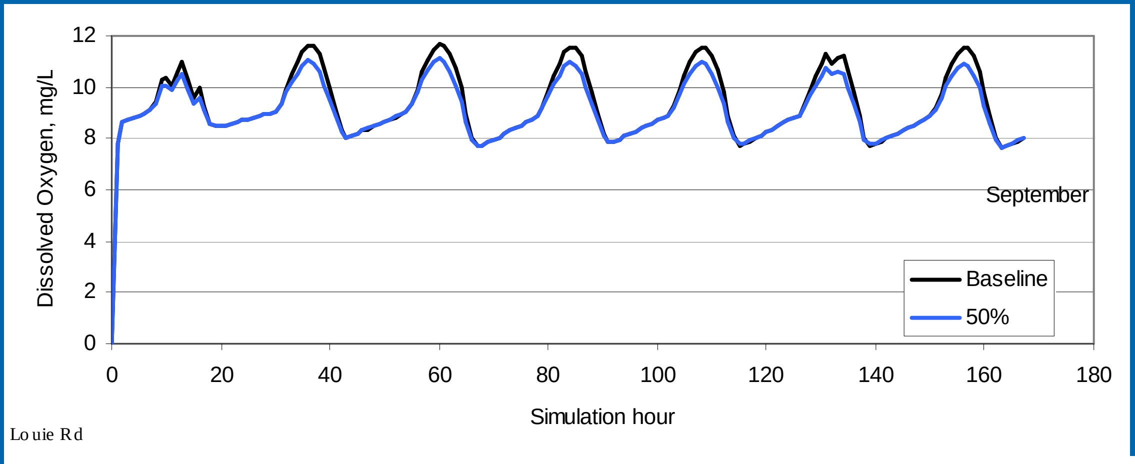
Woody Riparian (50%)

All temperatures cooler than baseline

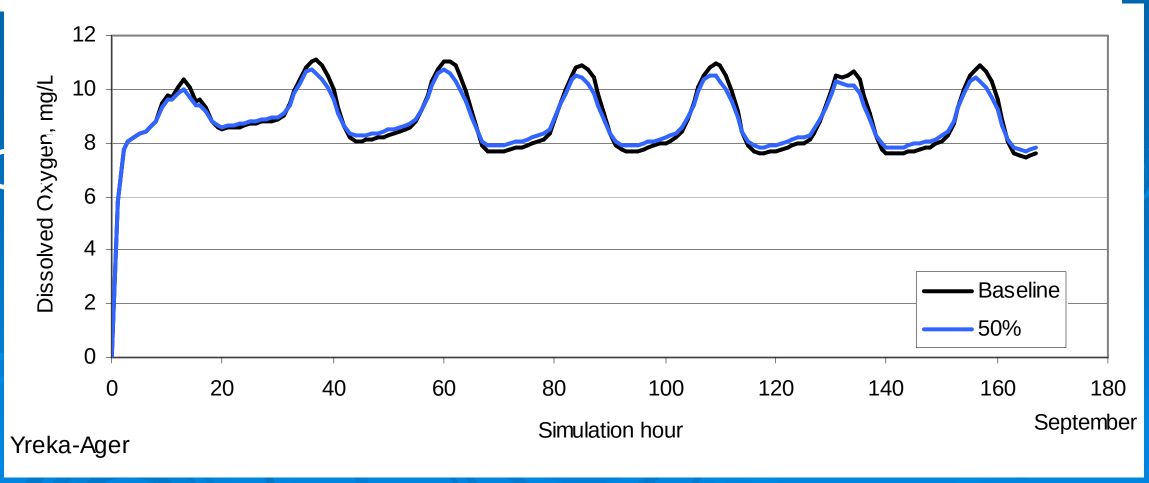


Riparian Shade: Dissolved Oxygen

Louie Rd (Sept)



Yreka Ager Rd (Sep



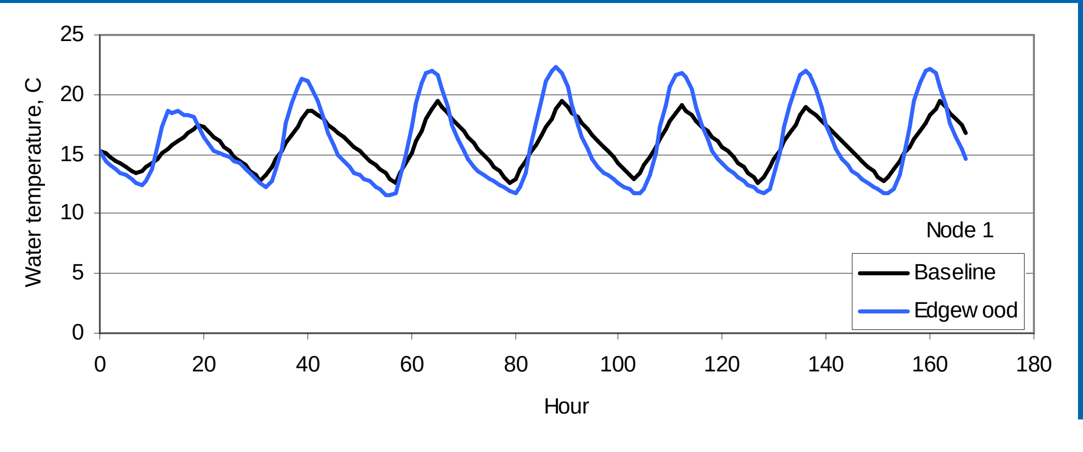
Dwinnell Dam Releases

- Objective: Identify impact of Edgewood Road "quality" and Dwinnell Reservoir release quality on Shasta River water temperature and dissolved oxygen
- Preliminary Findings: river returns to equilibrium temperature and saturation dissolved oxygen conditions quickly

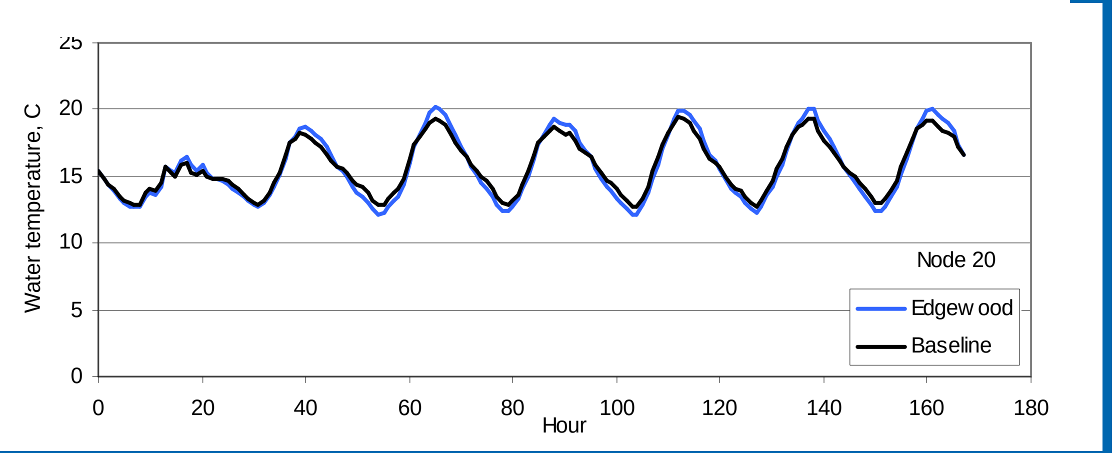
  Elevated nutrients at depth of reservoir may contribute to increased aquatic plant growth

Dwinnell Release: Temperature

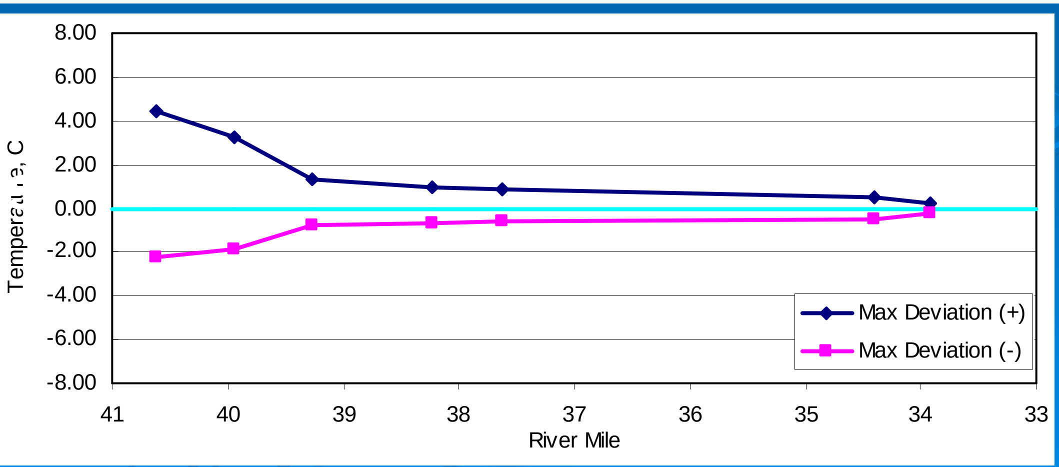
Below Dwinnell Dam



2 miles below Dwinnell



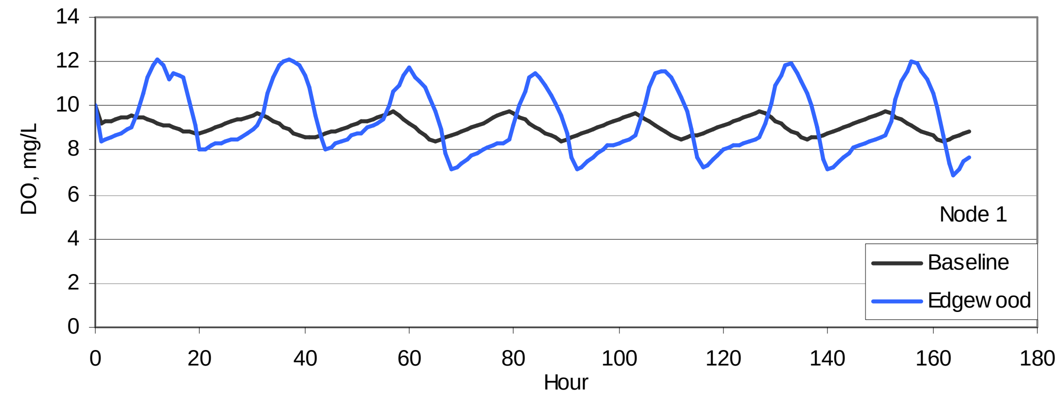
Longitudinal Difference



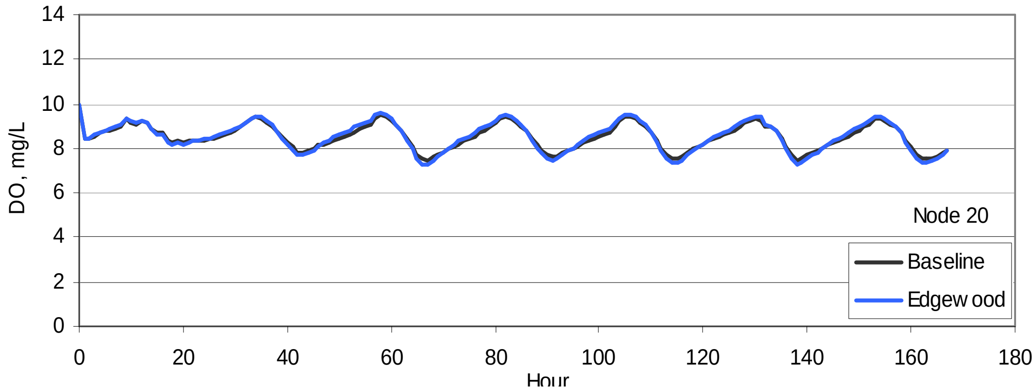
Edgewood Road

Dwinnell Release: Dissolved Oxygen

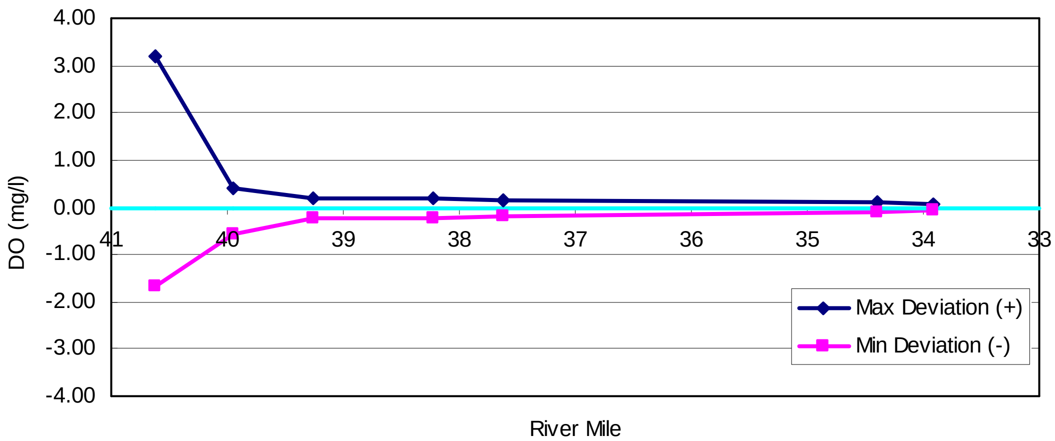
Below Dwinnell Dam



2 miles below Dwinnell



Longitudinal Differences



Edgewood Road

Impoundment Effects

- Objective: Assess potential impacts of impoundments on water quality (in-reservoir and in-river)
- Results: (pending)
  - Lake Shastina Limnology

Return Flows

- Objective: Identify impacts of 3 cfs return flow on water quality of Shasta River reaches between Dwinnell Dam and Highway 263.
- Preliminary Results: Return flow of this magnitude has a modest effect on temperature and dissolved oxygen of river reaches, the exception being the reach from Dwinnell Dam to Louie Road.

  Effects of nutrient and sediment inputs pending

Return Flows: Thermal Impact

			September			
River Mile	**Q1 (cfs)**	**C1 (°C)**	**Q2 (cfs)**	**C2 (°C)**	**C3 (°C)**	**CHANGE**
10	24.2	18.7	3	17.8	18.6	<0.3
10	24.2	18.7	6	17.8	18.5	<0.3
15	20.7	17.8	3	17.8	17.8	<0.3
15	20.7	17.8	6	17.8	17.8	<0.3
20	64.2	17.4	3	17.8	17.4	<0.3
20	64.2	17.4	6	17.8	17.4	<0.3
25	104.2	17.3	3	17.8	17.3	<0.3
25	104.2	17.3	6	17.8	17.3	<0.3
30	92.4	15.9	3	17.8	16.0	<0.3
30	92.4	15.9	6	17.8	16.0	<0.3
35	9.8	14.8	3	17.8	15.5	0.7
35	9.8	14.8	6	17.8	15.9	1.1

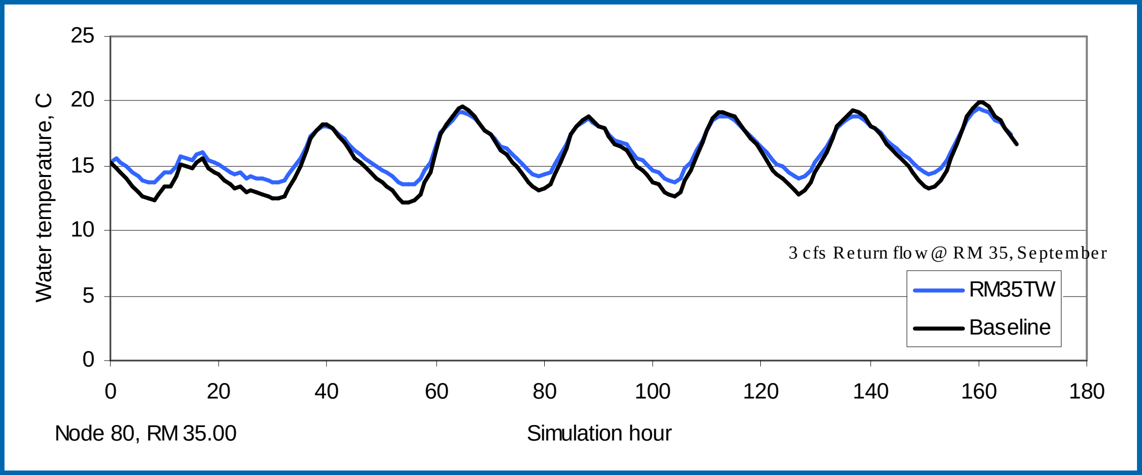
Q1, C1=Shasta River parameters

Q2, C2=Return Flow parameters

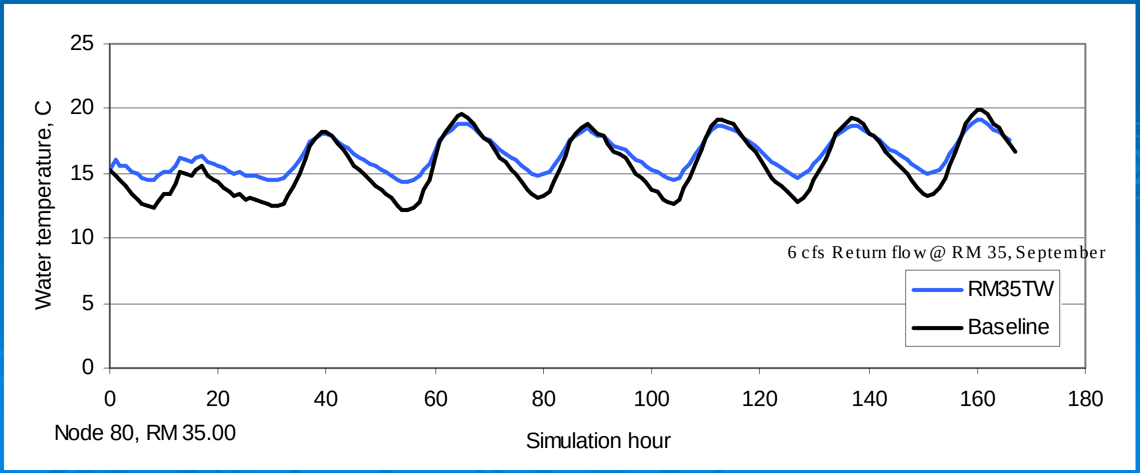
July and August results are similar

Tailwater Return: Temperature

3 cfs (RM 35)



6 cfs (RM 35)



Yreka Creek

- Objective: Identify potential impacts of Yreka Creek on mainstem Shasta River temperature, dissolved oxygen, and nutrients
- Results: pending

Increased Flows

- Objective: Identify the impacts of increased mainstem and Big Spring Creek flows on Shasta River temperature and dissolved oxygen (10%, 20% increases based on local flow)
- Results: pending

Benthic Algae

- <u>Objective</u>: Identify the impacts of increased and decreased benthic algal production on Shasta River dissolved oxygen conditions.
- <u>Preliminary Results</u>: pending

“Plumbing” Changes

- Objective: Identify potential opportunities for improving water quality by altering diversion locations
- Results: In progress

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Geographic Information Analysis

Objective: Compliment Shasta River water quality assessment; identify landscape-level sediment and nutrient loading rates

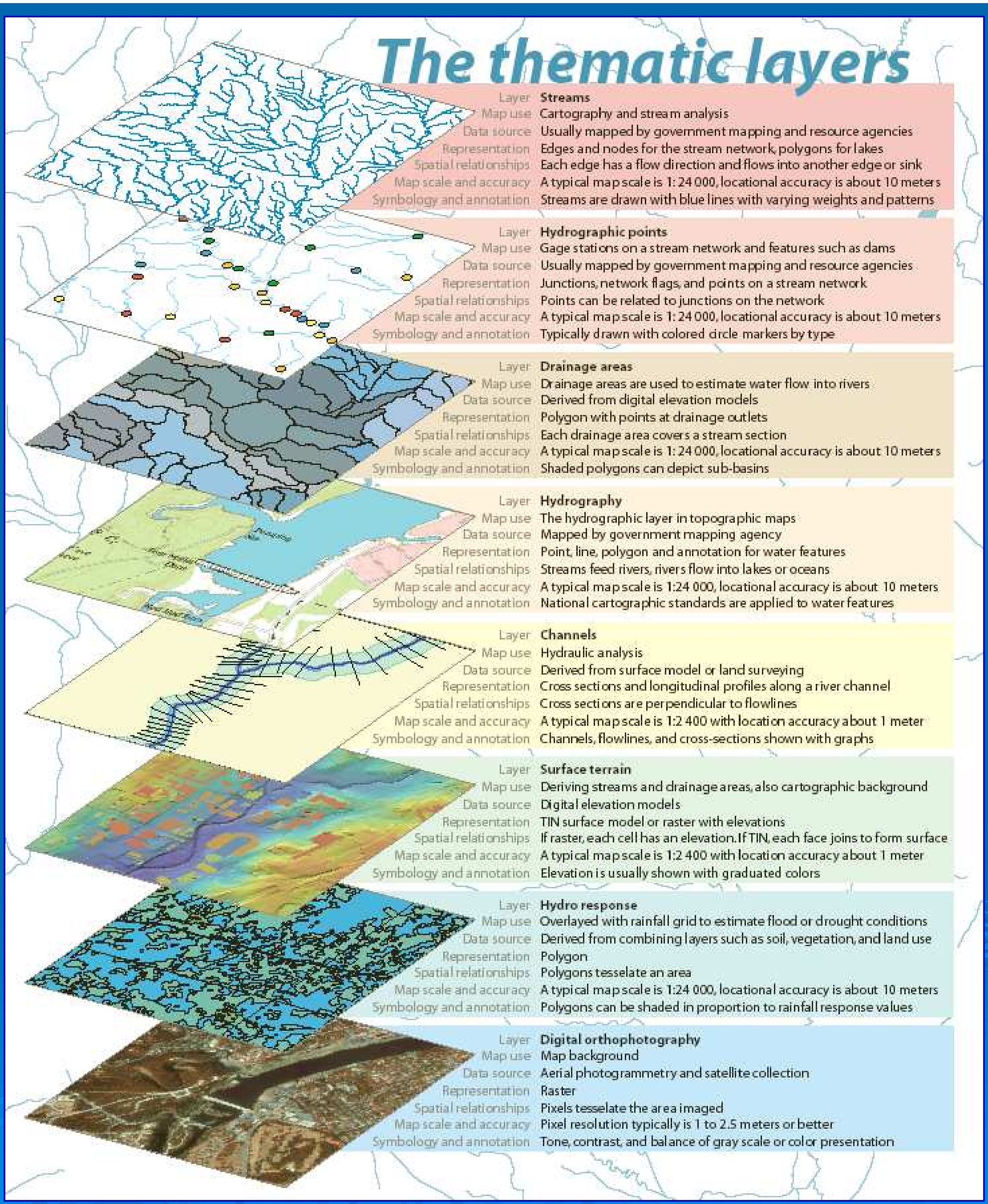
- Arc Hydro Data Model
  - Used extension for ESRI ArcGIS to delineate subwatersheds from water quality observation points
- Universal Soil Loss Equation
  - Approximate soil loss potential
- Simplex Nutrient Model v. 2.0
  - Approximate nutrient loading potential

ArcHydro

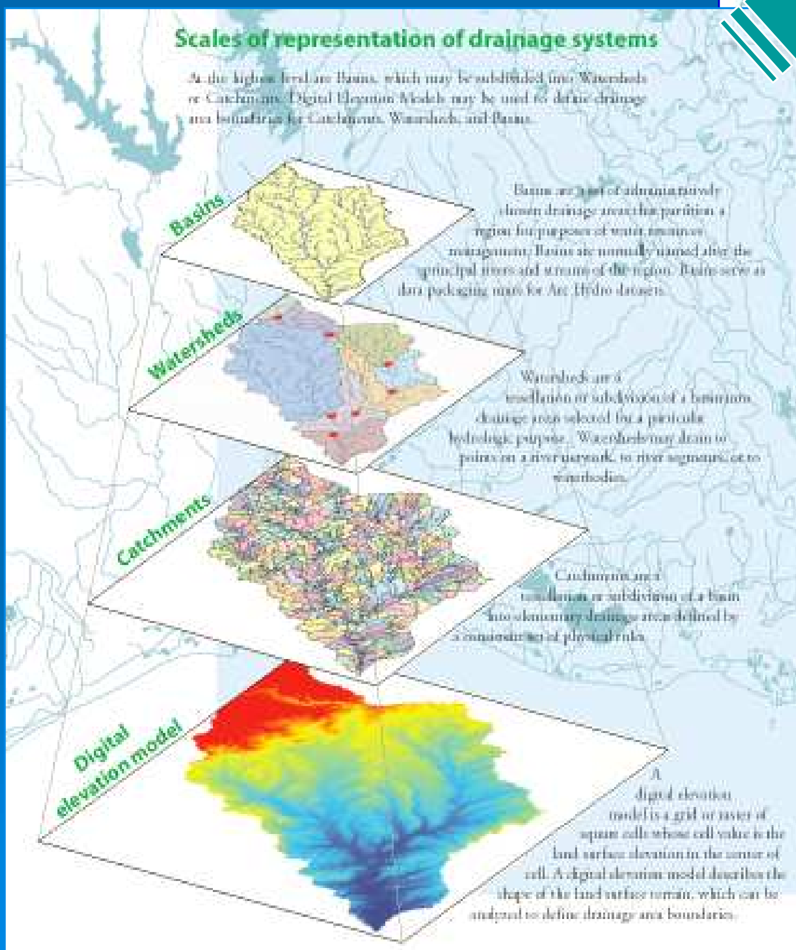
- The ArcHydro data model is a robust inter-relational geodatabase specific to hydrological resources.
  - Developed by Professor David Maidment (Univ. of Texas) and issued by ESRI, ArcHydro goes a long way toward standardizing the practice of water resource cataloging within a GIS.
  - Check out the following website for further information:
    - http://www.esri.com >> Search for ArcHydro
- Uses established methods for extracting hydrography from DEMs, creating a vector network within a geodatabase, establishing network topology with unique identifiers, and creating nested drainage basins for observation locations.

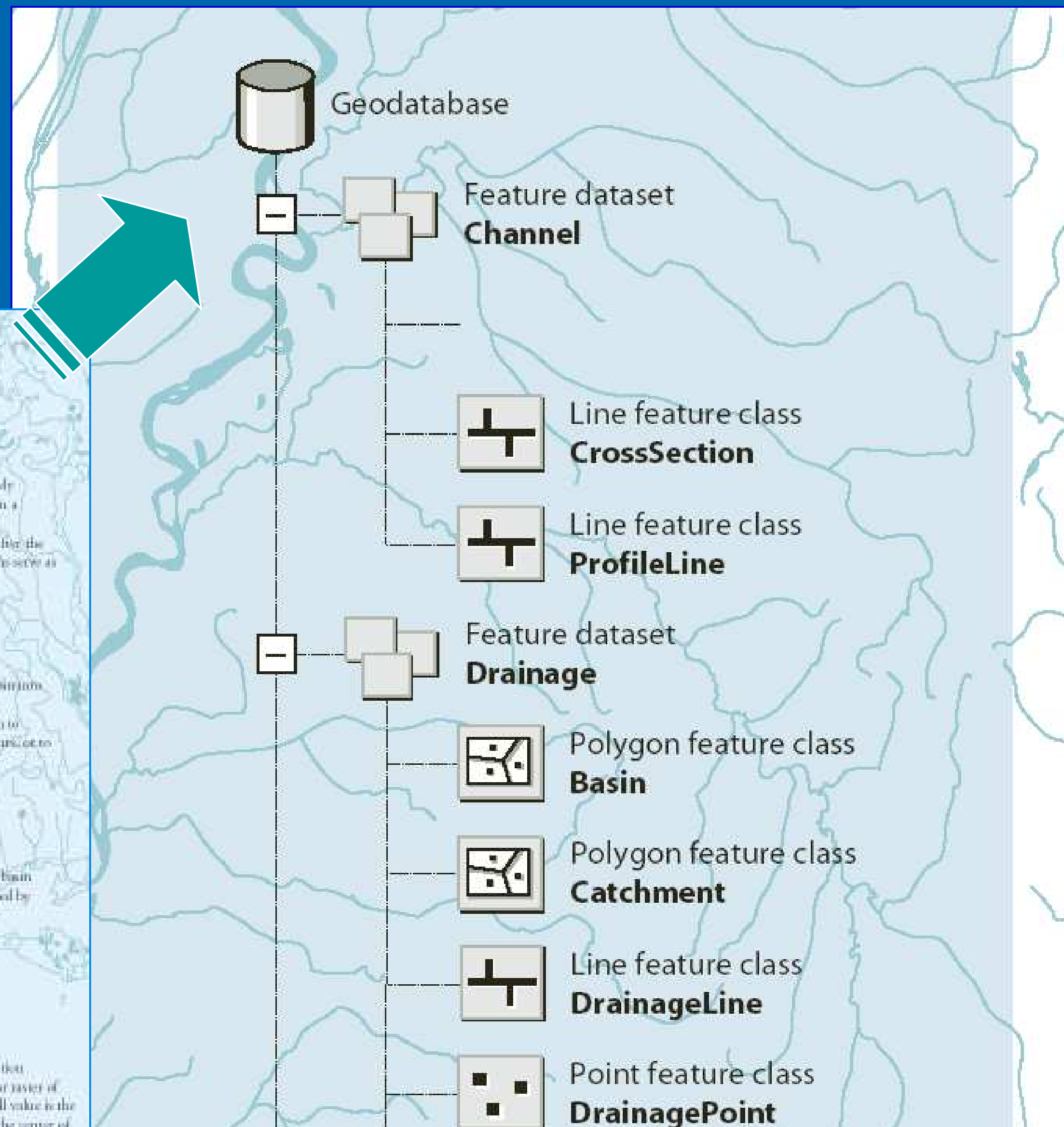
ArcHydro

- Hydrography
- Pour Points
- Watersheds
- Channels
- Routing



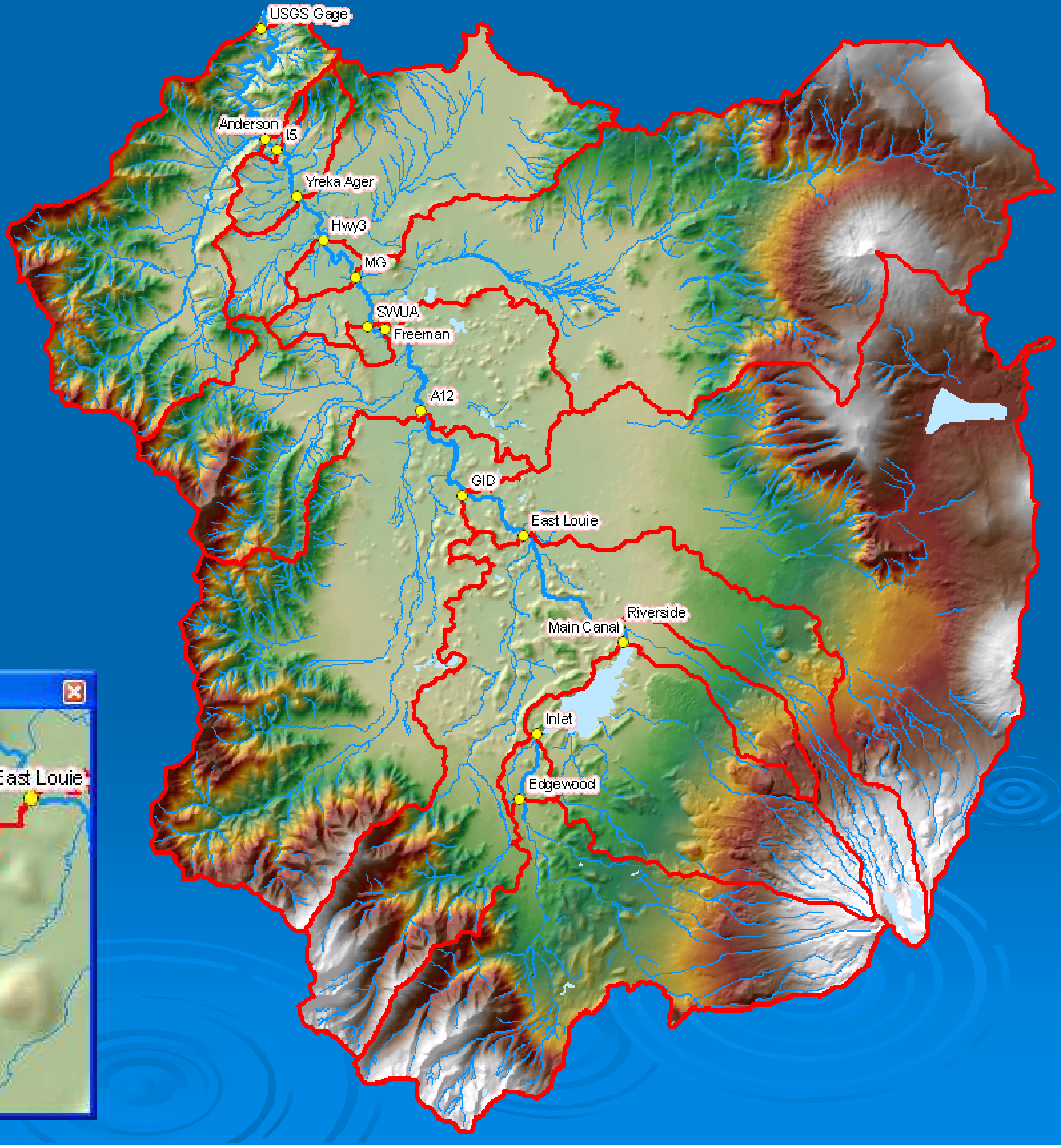
ArcHydro Geodatabase





ArcHydro sub-watersheds

- Used Lamphear's blue lines to recondition digital elevation model through ArcHydro tool set.
- Identified water quality observation locations within GIS.
- Generated upstream drainage boundaries or sub-watersheds for each observation location.



USLE
Universal Soil Loss Equation

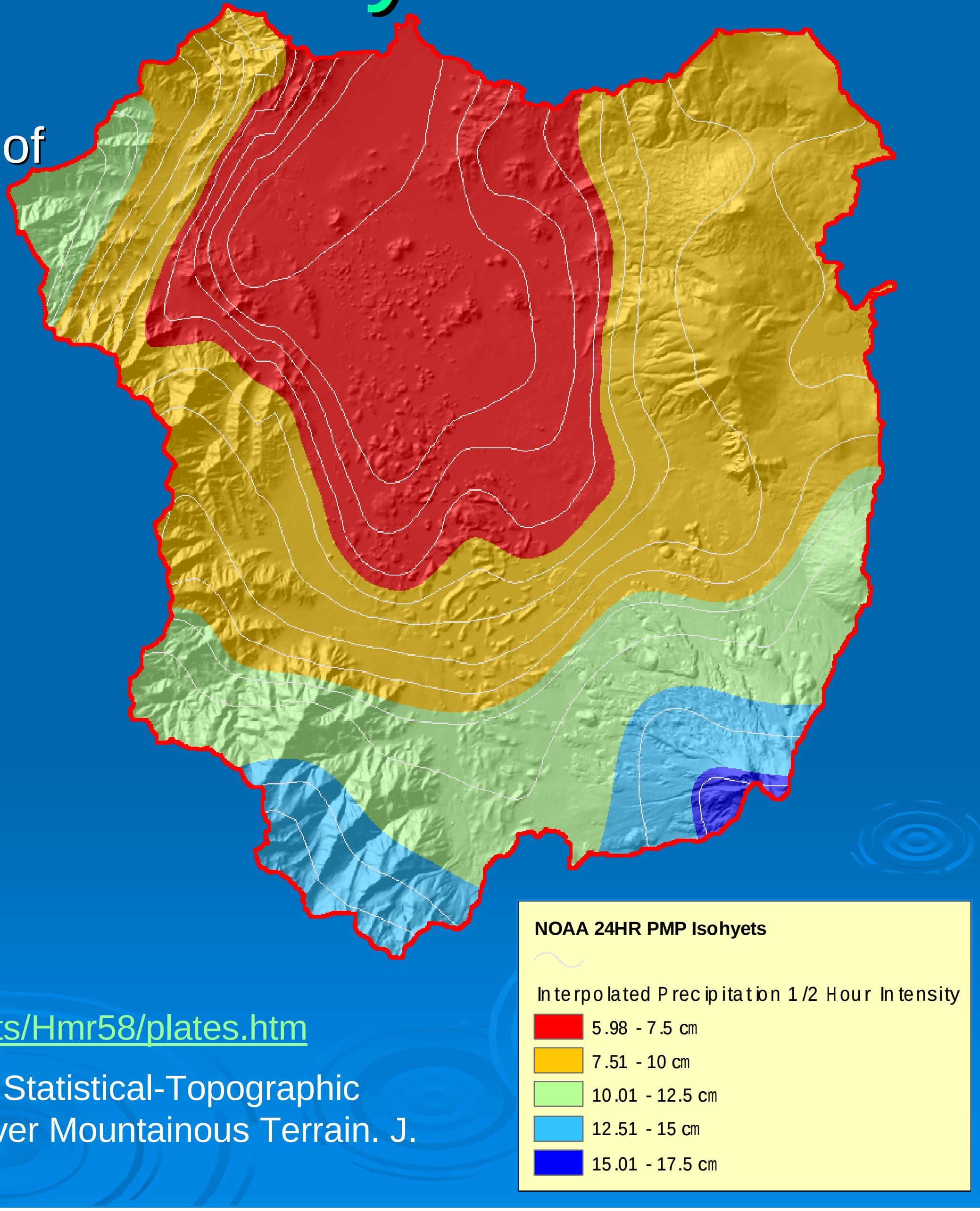
- Developed by the Soil Conservation Service (Wischmeier & Smith 1978) to approximate surface loss rates of soil due to rainfall → estimated in tons / acre or metric tons / hectare per event, such as a storm
- Uses 4 primary parameters:

  (R • C • K • SL • P)
  - R • Rainfall Intensity Factor
  - C • Cropping Factor (P • Conservation Practice)
  - K • Soil Erodibility Factor
  - SL • Slope Length / Slope Steepness Factor

Wischmeier, W.H., and D.D. Smith. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. USDA Handbook No. 537. U.S. Department of Agriculture, Washington, DC.

R • Rainfall Intensity Factor

- Rainfall Intensity is a function of kinematic energy (E) * storm intensity (I)
- Used NOAA storm data contours‡ to infer ½ hour intensity estimate for the watershed (HMR 58/59).
- Modeled each month as an event using PRISM (Parameter-elevation Regressions on Independent Slopes Model) monthly precipitation averaged from 1961- 1990 (Daly et al. 1994)



‡ http://www.nws.noaa.gov/oh/hdsc/On-line_reports/Hmr58/plates.htm

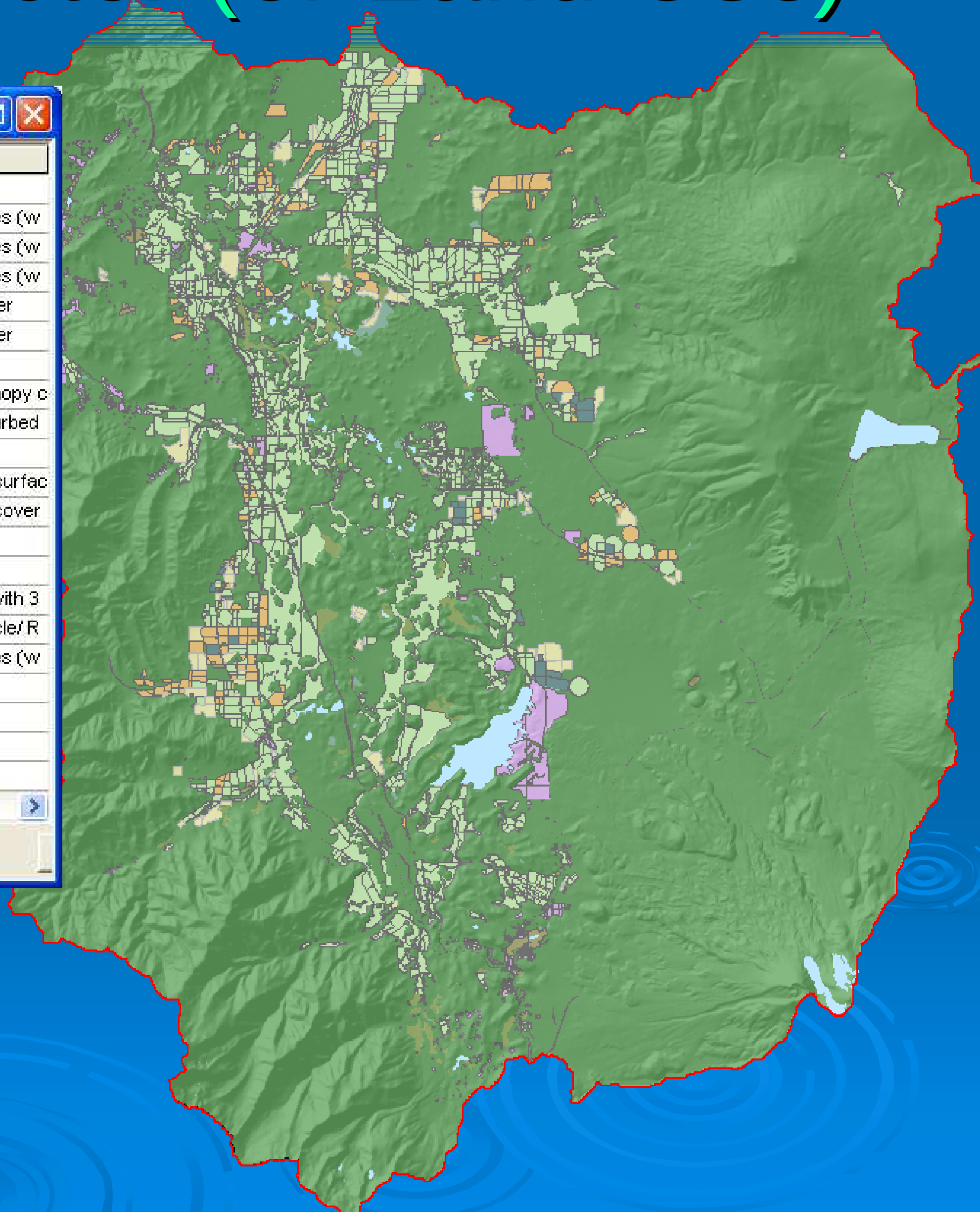
Daly, C., R.P. Neilson, and D.L. Phillips, 1994: A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountainous Terrain. J. Appl. Meteor., 33,140-158.

C • Cropping Factor (or Land Use)

Attributes of uslecfact.dat

LANDUSE	CBEST	CBEST_DESC
Open Water	0	
Low Intensity Residential	0.02	Lowest C factor for construction slopes (w
High Intensity Residential	0.02	Lowest C factor for construction slopes (w
Commercial/Industrial/Transportation	0.02	Lowest C factor for construction slopes (w
Bare Rock/Sand/Clay	0.011	0% canopy cover or 95% ground cover
Quarries/Strip Mines/Gravel Pits	0.011	0% canopy cover or 95% ground cover
Transitional Areas	0.7	10% mulch
Deciduous Forest	0.003	trees, 95% ground cover and 75% canopy c
Evergreen Forest	0.0001	100% canopy 100% 2inch duff undisturbed
Mixed Forest	0.001	75% canopy, 90% 2 inch duff
Shrubland	0.003	brush with average drop fall 6.5 feet, surfac
Orchards/Vineyards/Other	0.003	Orchard 95+ cover- 25%-75% raised cover
Grasslands/Herbaceous	0.01	Continuous annual grass
Pasture/Hay	0.01	Continuous annual grass
Row Crops	0.21	3 year Row and field crop sequence with 3
Small Grains	0.04	Barley/Wheat/Spring Fallow 2 year cycle/ R
Urban/Recreational Grasses	0.02	Lowest C factor for construction slopes (w
Woody Wetlands	0.0001	taken from undisturbed forest
Emergent Herbaceous Wetlands	0.0001	taken from undisturbed forest
Snow & Ice	0	
Fallow	1	standard

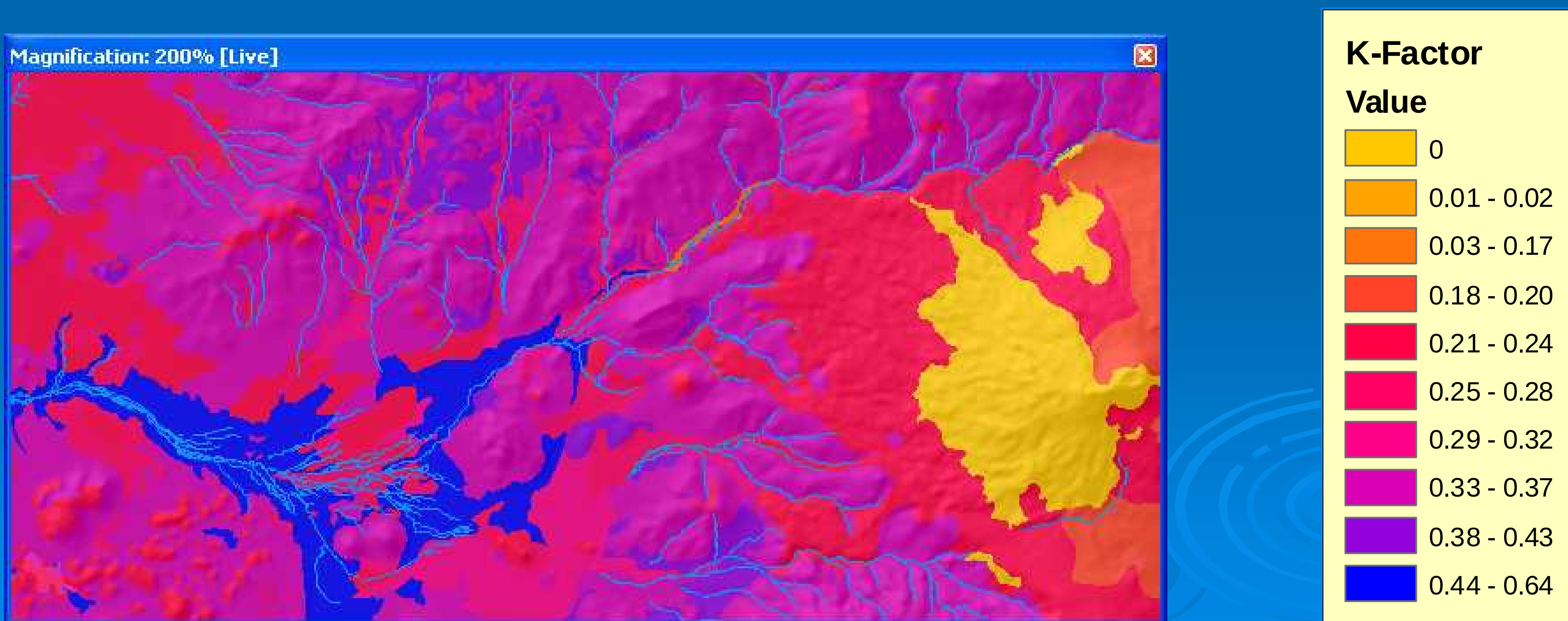
Record: 0 Show: All Selected Records (0 out of 21 Selected.)



The C-Factor is the ratio of soil loss from land cropped under specified conditions to corresponding loss under tilled, continuous follow conditions.

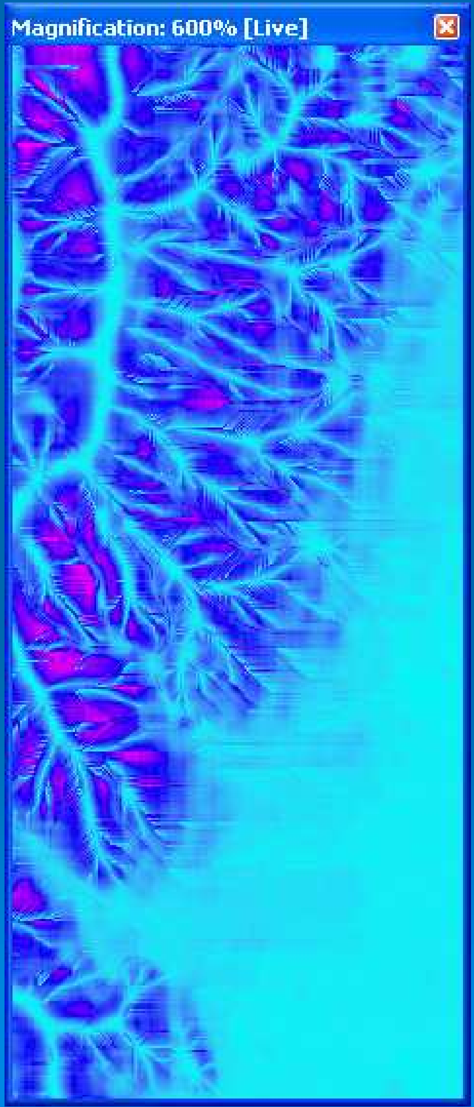
K • Soil Erodibility Factor

- Used a combination of NRCS's SSURGO (1:24000) soils data and STATSGO (1:250000) where SSURGO was unavailable.



SL • Slope Length Factor

Used program for ArcInfo developed by Bureau of Land Management to calculate the Slope Length – Slope Steepness, or terrain, Factor used in USLE.



- /*---
- /* AUTHOR: Jacek S. Blaszczynski, Physical Scientist
- /* BLM NARSC, Original coding, 04/99
- /*   Revision and additions of LSFACTOR2, 02/2000
- /*---------------------------- Purpose ---
- /*
- /* To calculate grids of values for the terrain factor of the Revised
- /* Universal Soil Loss Equation from digital elevation model data using the
- /* empirically based LS factor equation described in the BLM RUSLE diskette
- /* (Simanton, 1987) and physical-process based LS equation developed
- /* by Moore and Wilson (1992) and Mitasova (1993).

- /*   L is the slope-length factor, is the ratio of soil loss from the
- /*   field slope length to that from a 72.6-ft length under identical
- /*   conditions;
- /*
- /*   S is the slope-steepness factor, is the ratio of soil loss from
- /*   the field slope gradient to that from a 9-percent slope under
- /*   otherwise identical conditions;
- /*

Simplex v. 2.0 Nutrient Model

- Intended to evaluate runoff and nutrient loading statistics for a given local area (i.e., land use/land cover and soil characteristics).
  - Runoff
  - Nitrogen
  - Phosphorus
- Version 1.0 was originally written at the University of Kansas. Version 2.0 is modified to allow greater flexibility in running the model within a GIS and was developed at the University of California, Davis.
- Modeling approaches for estimating watershed nutrient runoff include the use of 1) export coefficients, 2) chemical simulation models, and 3) loading functions .
  - 1) Export coefficients typically describe an average unit area for nutrient loads per year runoff.
  - 2) Chemical simulations are much more accurate, however they are data intensive and require extensive parameterization with field data.
  - 3) Loading approaches tend to be a compromise between export coefficients and chemical simulations. Loading functions therefore provide a useful means of estimating nutrients over large areas.

Simplex v. 2

- Combination of Soil Hydric Group and Land Use

LU/LC Description ...

LULC_Code	LULC_Desc
NR	Riparian Vegetation
UC	Commercial
UV	Vacant
NC	Native Classes Unsegregated
P	Pasture
NV	Native Vegetation
NW	Water Surface
S	Semiagricultural & Incidental
UI	Industrial
T	Truck, Nursery and Berry Crop:
U	Urban

SCS Curve Table

LULC_Code	crv_c	crv_d	crv_b
NV	0	0	0
G	0	0	0
NW	0	0	0
F	0	0	0
P	0	0	0
NR	0	0	0
S	0	0	0
T	0	0	0
C	0	0	0
D	0	0	0
UV	0	0	0
U	0	0	0
UI	0	0	0

new_coef.dbf

LULC_Code	Phos	Nitro
C	0.00000	0.00000
D	0.00000	0.00000
F	0.00000	0.00000
G	0.00000	0.00000
I	0.00000	0.00000
NC	0.00000	0.00000
NR	0.00000	0.00000
NV	0.00000	0.00000
NW	0.00000	0.00000
P	0.00000	0.00000
S	0.00000	0.00000
T	0.00000	0.00000
U	0.00000	0.00000
UC	0.00000	0.00000
UI	0.00000	0.00000
UL	0.00000	0.00000
UR	0.00000	0.00000
UV	0.00000	0.00000
V	0.00000	0.00000

Simplex Equations

- Simplex Input Parameters:
  - ***C*** = CN Soil Conservation Service (SCS) curve value
  - ***A*** = units area of analysis
  - ***R*** = rainfall (cm)
  - ***P*** = Phosphorus (kg/event) Coefficients
  - ***N*** = Nitrogen (kg/event) Coefficients
- Curve numbers empirical relationship with S (s = maximum potential retention)
  - Dskt = (2540/***C***) – 25.4; where ***C*** is curve number
- Qkt = Q Actual runoff depth – this is based on the CN and the potential retention.
  - Qkt = ((***R*** - (0.2*Dskt))^2 / (r + (0.8*Dskt)))
- Wash off function from Amy et al. 1974
  - Wkt = 1 ((exp (1-8.1*Qkt)))
- Particle accumulation on surfaces is a mass balance process (Novotny and Olem 1994)
  - Mwkt = Wkt * (***p*** /0.12) * (1- (exp(-0.12)))
  - ***p*** = nutrient particle of interest
- Calculate loading for study area
  - ***P*** = Mwkt * ***Area***
  - ***N*** = Mwkt * ***Area***

Outline

- Introductions
- TMDL scope, schedule, and status
- Analytical tools – scope and status
  - Water quality model
  - Benthic algae model
  - Mass balance, mixing, and residence time calculations
  - Productivity calculator
- Water quality model scenarios
- Geographic information analysis
- Implementation Plan concepts
- Feedback – Q &A

Preliminary Implementation Plan Concepts

- Regional Water Board shall increase efforts to work cooperatively with NRCS, Shasta Valley RCD, Shasta CRMP, and Siskiyou Cty to provide technical support and info to landowners
- Regional Water Board shall work cooperatively with CDFG to implement the Coho Recovery Strategy
- The Regional Water Board shall use waste discharge requirements, general waste discharge requirements, and waivers of waste discharge requirements to regulate timber harvest activities.

Implementation Plan Concepts cont.

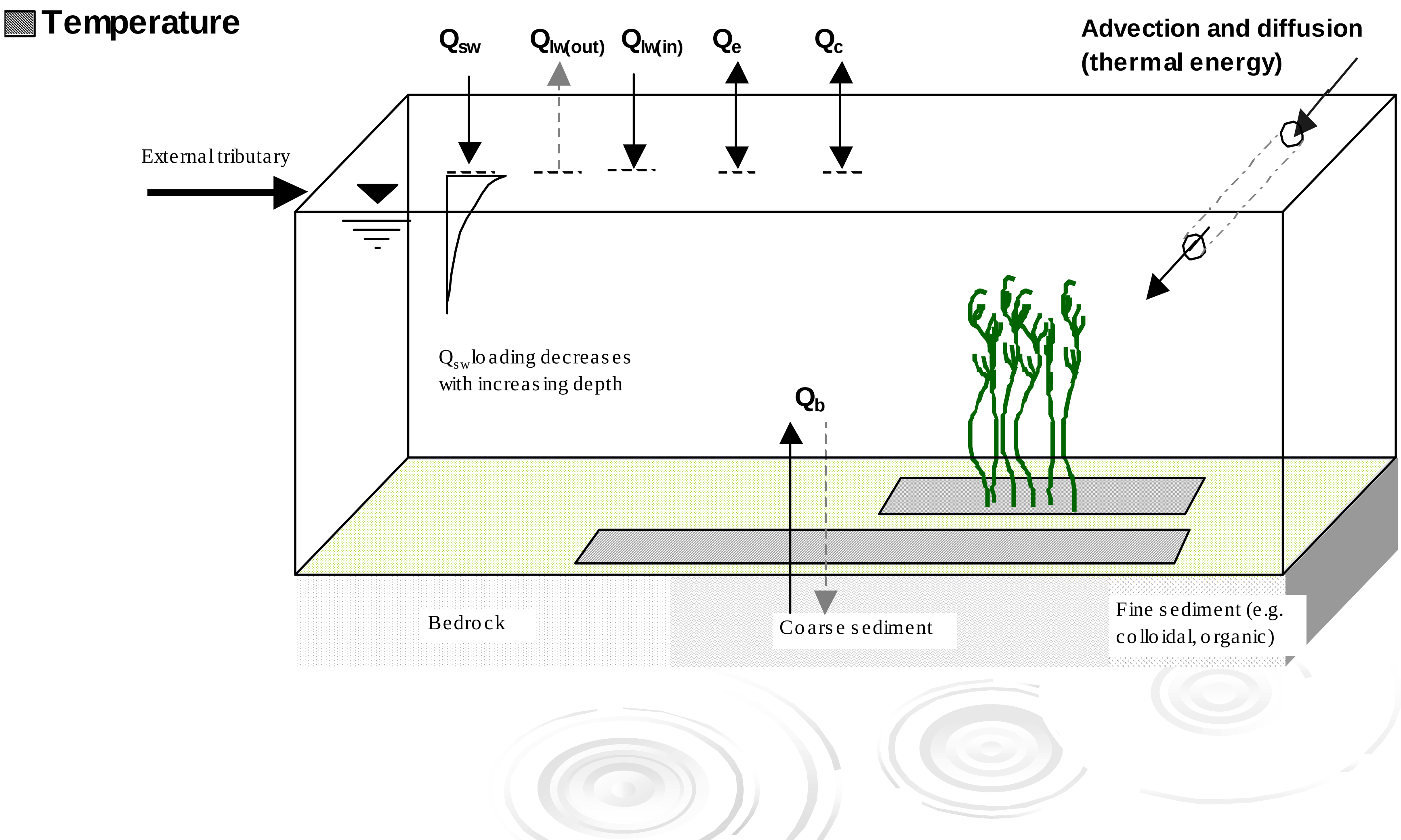
- Prohibition of riparian vegetation removal that results in net increase of solar radiation loads
- Farms and ranches withdrawing water directly from the Shasta River and its tributaries, including near-stream zones with aquifer interconnection shall develop a Ranch Water Quantity-Quality Conservation Plan
- Design and complete restoration and conservation projects to improve water temperature and dissolved oxygen conditions using prioritized sites with greatest beneficial use potential

Implementation Plan Concepts cont.

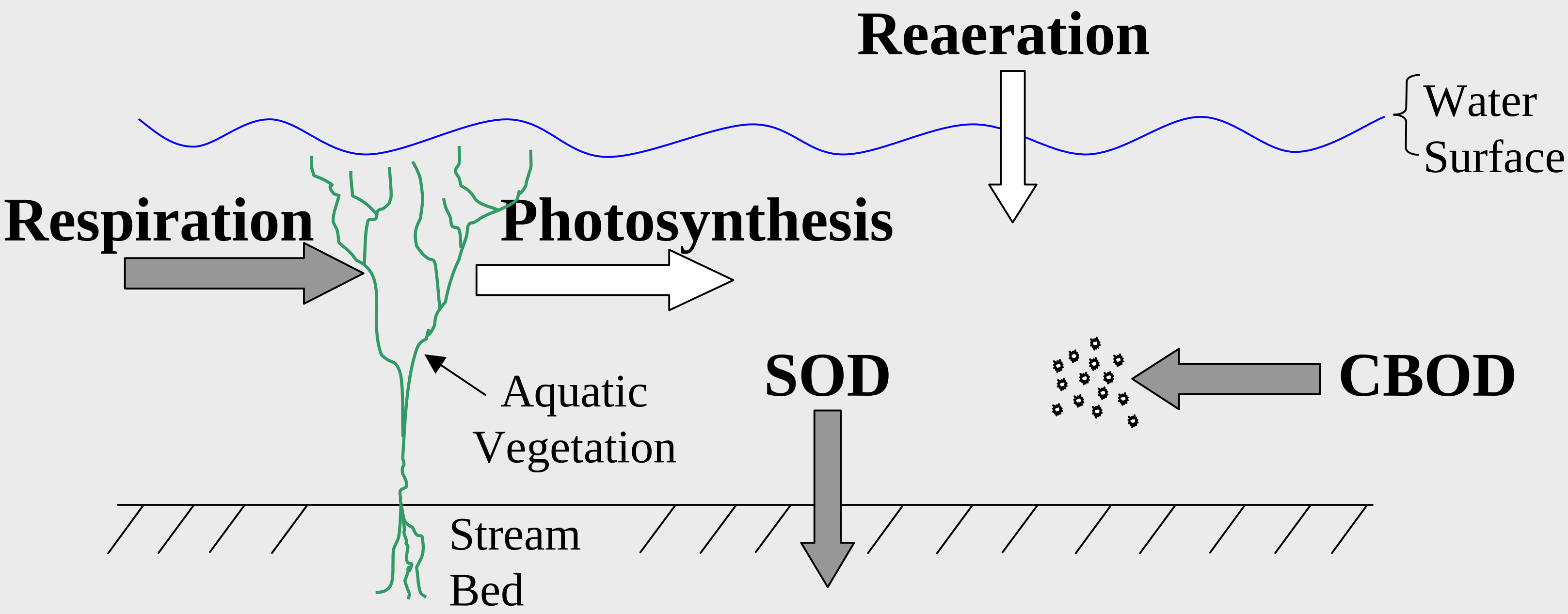
- Where feasible, install systems that reuse and/or treat tailwater
- Evaluate opportunities to modify impoundments to improve water quality
- Reduce demand for water by promoting efficient water management practices that are economical, reliable, and practical

Questions/Comments?

Water Temperature Processes



Factors Affecting Dissolved Oxygen in the Shasta River



Dissolved Oxygen Sources

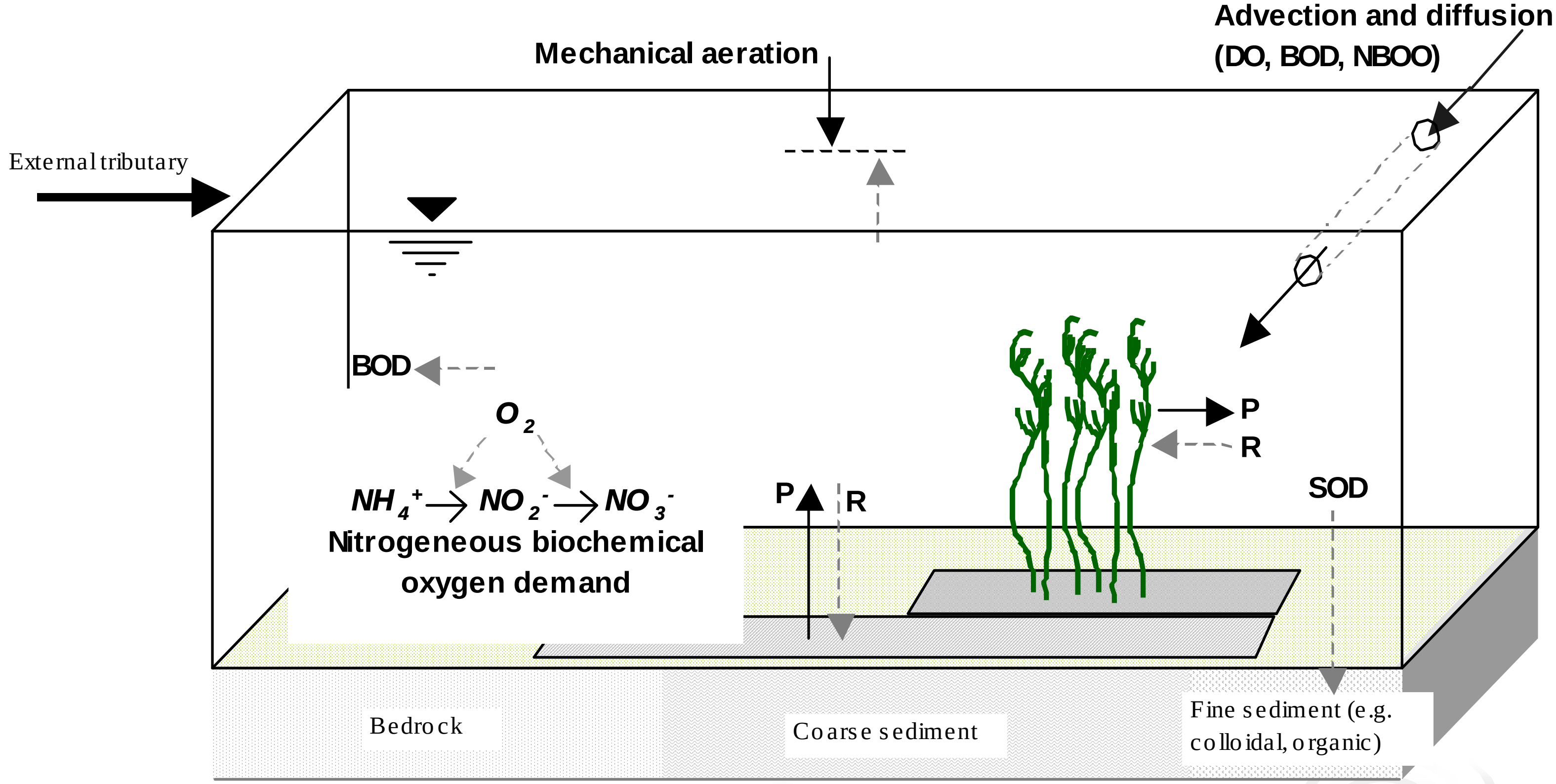
- Reaeration
- Photosynthesis

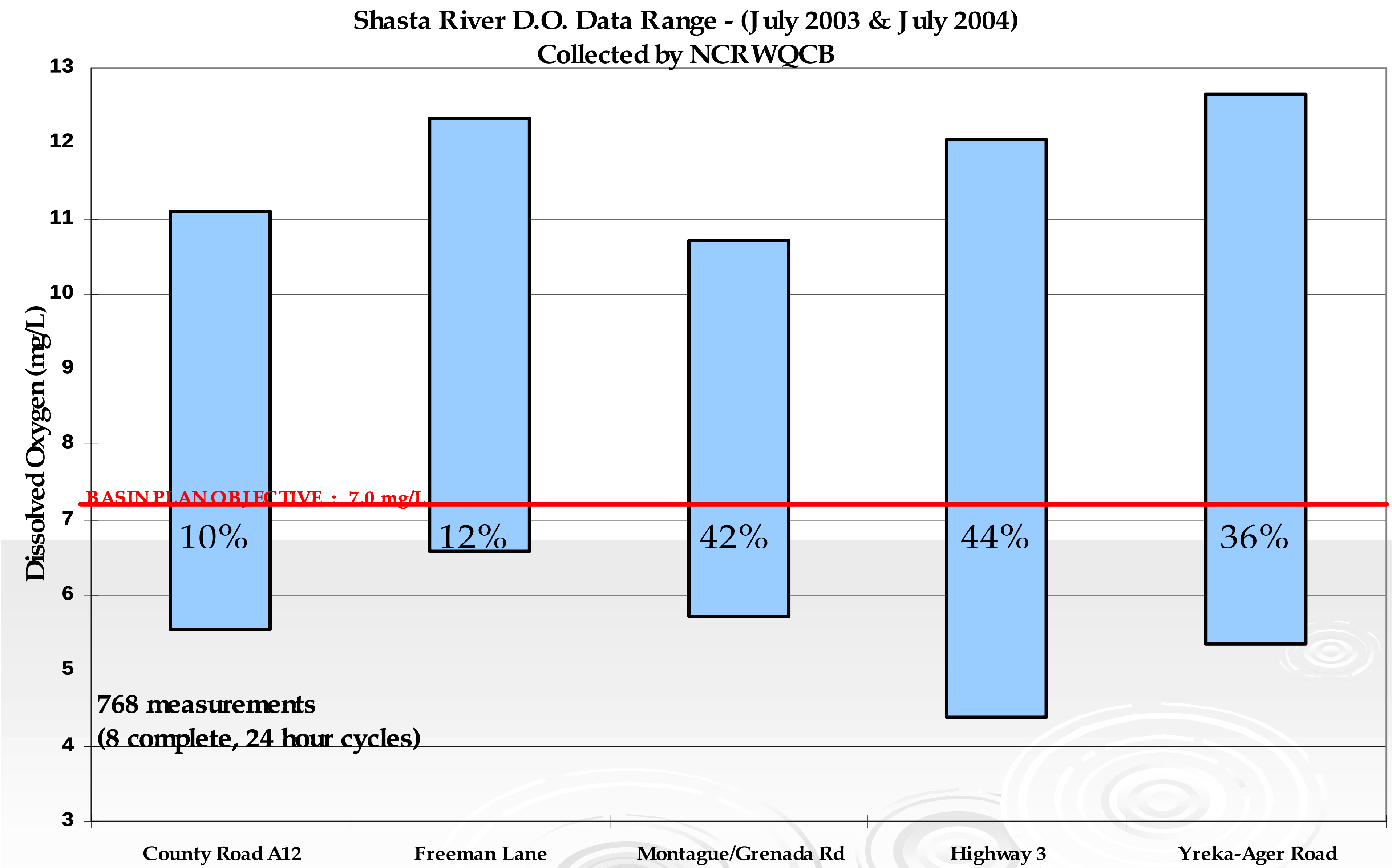
Dissolved Oxygen Sinks

- Respiration
- Sediment Oxygen Demand (SOD)
- Carbonaceous Deoxygenation (CBOD)

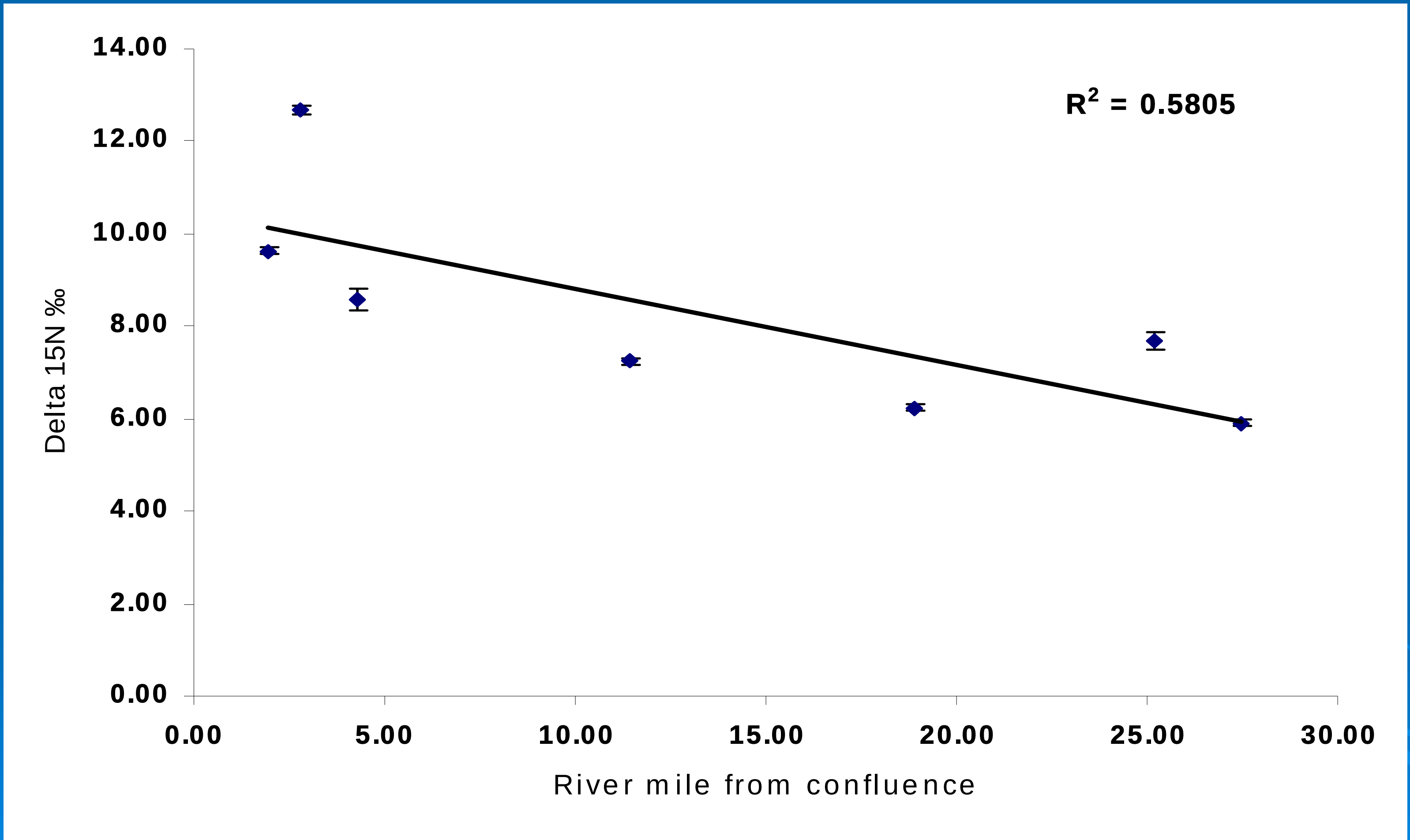
Dissolved Oxygen Processes

- Oxygen




Shasta River D.O. Data Range - (July 2003 & July 2004)
Collected by NCRWQCB
Dissolved Oxygen (mg/L)
13
12
11
10
9
8
7
6
5
4
3
BASIN PLAN OBJECTIVE : 7.0 mg/L
10%
12%
42%
44%
36%
768 measurements
(8 complete, 24 hour cycles)
County Road A12
Freeman Lane
Montague/Grenada Rd
Highway 3
Yreka-Ager Road

Stable nitrogen isotope vs. river mile for Elodea canadensis



Pristine systems have $\delta^{15}N$ levels of 0 ‰ (Steffy and Kilham 2004)

Stable nitrogen isotope vs. river mile for suspended organic material